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Transmission of Big Data via LEO/Terrestrial Laser Links: A Revolution for Satellite Applications

Presented by :
1) Miss. KOUBI Bouchra
2) Miss. BOURELEM Manel

Before the jury composed of:

Dr MERADI Abdelhafid	MCA	UAT.BB (Ain Temouchent)	President
Dr KANOUN Ahmed Ali	MRA	CDS (Oran)	Examiner
Dr DEBBAL Mohammed	MCA	UAT.BB (Ain Temouchent)	Supervisor
Dr KOURDI Zakarya	MRA	CDS (Oran)	Co-Supervisor

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Thanks

We thank ALLAH the Almighty for giving us the courage and the will to complete this work as part of our master's thesis.

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We cannot end without expressing our gratitude to all the members of our families who supported and advised us throughout this work, especially our mothers and fathers.

Dedication:

To my dear mother
For the love she always gave me"
To my father
For your unwavering support, andall the help he gave me during my studies.
May God protect you and grant you a long life.”
HASmy brothers and all my family
Thank you for your encouragement, your love

All my friends without exception **,** Thank you for all the beautiful moments and your support in difficult times.
To my dear partner
I thank you for your dedication, and I sincerely wish you happiness, health and success in all aspects of your life, whether personally or professionally."

Manuel

Dedication

With all my feelings of respect, I dedicate my graduation and my joy
To my paradise, to the apple of my eye, to the source of my joy and my happiness, my moon and the thread of hope that lights my path, my other half, Mom
To the one who made me a woman, my source of life, love and affection, to my supporter who has always been by my side to support and encourage me, to my prince, Dad.
To my brothers for the love they have for me, who have never stopped advising, encouraging and supporting me throughout my studies.
To my dear friends, I thank you for your friendships dear to my heart, and I wish you all the happiness in the world.
To all my family for their encouragement.
Without forgetting my partner for their moral support, patience and understanding throughout this project.

Bouchra

Résumé

Ce sujet décrit une approche révolutionnaire pour transmettre de grands volumes de données dans des applications satellitaires via des liaisons laser d'intercommunication au sol (LIGL) avec des satellites en orbite terrestre basse (LEO). Dans ce système innovant, des transferts de données de grande capacité sont réalisés grâce à la technologie laser, garantissant une communication rapide et efficace entre les stations au sol et les satellites LEO. En exploitant la puissance des lasers, le système facilite la transmission transparente du Big Data, surmontant ainsi les limites posées par les méthodes traditionnelles de radiofréquence.

La technologie exploite des faisceaux laser précis pour établir des liens d'intercommunication fiables, permettant l'échange rapide d'ensembles de données importants. Cette approche améliore non seulement considérablement les taux de transmission des données, mais garantit également des capacités de faible latence et de bande passante élevée, essentielles pour les applications modernes exigeant un traitement et une analyse de données en temps réel.

De plus, l'utilisation de liaisons terrestres d'intercommunication laser offre une sécurité accrue et une vulnérabilité réduite aux interférences, ce qui en fait une solution idéale pour les communications par satellite sécurisées et critiques. Le résumé met en évidence le potentiel de cette technologie avancée pour révolutionner les applications satellitaires, en particulier dans les domaines nécessitant une diffusion rapide des données, tels que l'observation de la Terre, la recherche scientifique et la gestion des catastrophes.

Mots-clés : Optique, Laser, intercommunication, Satellite, Big data, Optsys software.

Abstract

This topic describes a revolutionary approach to transmitting large volumes of data in satellite applications via ground-based laser intercommunication links (LIGL) with satellites in low earth orbit (LEO). In this innovative system, high-capacity data transfers are achieved using laser technology, guaranteeing fast, efficient communication between ground stations and LEO satellites. By harnessing the power of lasers, the system facilitates the seamless transmission of Big Data, overcoming the limitations posed by traditional radio frequency methods.

The technology exploits precise laser beams to establish reliable intercommunication links, enabling the rapid exchange of large datasets. This approach not only significantly improves data transmission rates, but also guarantees low latency and high bandwidth capabilities, essential for modern applications requiring real-time data processing and analysis.

In addition, the use of terrestrial laser intercommunication links offers enhanced security and reduced vulnerability to interference, making it an ideal solution for secure, mission-critical satellite communications. The abstract highlights the potential of this advanced technology to revolutionize satellite applications, particularly in areas requiring rapid data dissemination, such as Earth observation, scientific research and disaster management.

Keywords: Optics, Laser, intercommunication, Satellite, Big data, Optsys software.

ملخص

تصف هذه الورقة البحثية نهجاً ثورياً لنقل كميات كبيرة من البيانات في التطبيقات الأقمار الصناعية عبر وصلات الاتصالات البينية الليزرية الأرضية (LIGL) مع الأقمار الصناعية في المدار الأرضي المنخفض (LEO). في هذا النظام المبتكر، يتم تحقيق عمليات نقل بيانات عالية السعة باستخدام تقنية الليزر، مما يضمن اتصالاً سريعاً وفعالاً بين المحطات الأرضية والأقمار الصناعية في المدار الأرضي المنخفض. ومن خلال تسخير قوة الليزر، يسهّل النظام النقل السلس للبيانات الضخمة، متغلباً بذلك على القيود التي تفرضها طرق الترددات الراديوية التقليدية.

تستغل هذه التقنية أشعة الليزر الدقيقة لإنشاء وصلات اتصال بينية موثوقة، مما يتيح التبادل السريع لمجموعات البيانات الكبيرة. لا يحسن هذا النهج من معدلات نقل البيانات بشكل كبير فحسب، بل يضمن أيضاً انخفاض زمن الاستجابة وقدرات عرض النطاق الترددي العالي، وهو أمر ضروري للتطبيقات الحديثة التي تتطلب معالجة البيانات وتحليلها في الوقت الفعلي.بالإضافة إلى ذلك، يوفر استخدام وصلات الاتصال البيني بالليزر الأرضية مزيدًا من الأمان وتقليل التعرض للتشويش، مما يجعله حلاً مثاليًا للاتصالات ا الأقمار الصناعية الآمنة والحرجة للمهام. يسلط الملخص الضوء على إمكانات هذه التكنولوجيا المتقدمة لإحداث ثورة في تطبيقات الأقمار الصناعية، لا سيما في المجالات التي تتطلب نشر البيانات بسرعة، مثل رصد الأرض والبحث العلمي وإدارة الكوارث.

الكلمات المفتاحية:البصريات، الليزر، الاتصالات البينية، الأقمار الصناعية، البيانات الضخمة، برمجياتOptsys.

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General Introduction

In a world where the amount of data generated and exchanged grows exponentially, the efficient transmission of Big Data becomes a crucial issue. Traditional transmission methods, such as fiber optic cables and radio wave transmissions, are quickly reaching their limits in terms of bandwidth and ability to meet growing demand.

Laser satellites have many advantages over conventional satellites, making them essential in the field of communications. They have significantly accelerated and improved communications between different regions of the world. However, the main complexity of a laser satellite optical transmission system lies in the pointing system. Thus, it can happen that the laser beams sometimes partially or completely miss the receiving satellite due to continuous vibrations of the pointing system, caused by internal and external sources. Various methods are used to overcome this problem and, therefore, improve the quality of communication [1] [2] [3].

The Low Earth Orbit (LEO) system plays a critical role in transmitting data via laser link between satellites and Earth. This orbit, located at a relatively low altitude compared to other orbits, offers significant advantages for communication, such as reduced latency and faster transmission speeds. Low-orbit satellites can provide wider coverage and more efficient connectivity for large-scale data transmission. Additionally, due to their proximity to Earth, low-orbit satellites require less power for communications, making them more efficient at transmitting large volumes of data. In summary, the low-orbit system plays a key role in the efficient transmission of massive data via laser link between satellites and Earth. [4.5]

Faced with this reality, space technologies are emerging as a promising alternative to meet the growing needs for massive data transmission. Among these technologies, low-orbit (LEO) laser link data transmission stands out for its ability to offer high data rates and low latency, making it an attractive solution for transmitting Big Data on a global scale. .

This research paper aims to provide a comprehensive overview of laser satellites and their role in communications in the era of global connectivity.

We can summarize our work in three chapters

The first chapter is focused on the new generations of satellites used Laser for intercommunication, optical intercommunication systems, transmission structure and FSO, OWC technologies, etc.

The second chapter is devoted to big data transmissions and setting specifications and we have represented some equations by calculating the different parameters of a link report.

OptiSystem simulation software , which we used to evaluate our IsOWC(inter satellite optical wirless communication) link . We will examine the results from our modeling in detail, providing feedback and engaging in discussions around these results.

Finally, a conclusion will end this dissertation summarizing the main tasks accomplished.

Chapter 1: General information on the satellite domains

I.1 Introduction

The use of laser technology in satellites for intercommunication represents a major advance in the space domain. Laser communication systems offer significant benefits such as fast and secure data transmission, reduced latency and reduced dependence on terrestrial infrastructure.

However, this technology is not without challenges, particularly due to the precision required for pointing laser telescopes from satellites to ground stations, as well as atmospheric effects that can disrupt laser beams as they pass Earth.

Despite these challenges, laser communications offer promising prospects for the future of space communications, with high transmission speeds and enhanced security. Initiatives such as Amazon's Project Kuiper and SpaceX's Starlink constellation illustrate the growing adoption of this revolutionary technology. By continuing to overcome technical obstacles and develop common standards, laser communications are set to redefine space connectivity and open new possibilities for commercial, military and government applications [I.1] [I.2] [I .3].

In this chapter, we will discuss various exciting topics related to optical communications. We will begin by exploring the world of satellites, these orbiting devices that play a crucial role in communications. Next, we'll dive into optical intercommunication systems, which enable the transfer of data through light signals. We will also look at the transmission structure used to efficiently carry these signals. In addition, we will look at FSO (Free- Space) technologiesOptics), which exploit the vacuum of space to transmit data at high speed, as well as optical wireless communications (OWC) which offer innovative solutions for wireless connectivity.

I.2. Satellites

Artificial satellites appeared in the late 1950s, realizing an ambitious vision of engineer Arthur C. Clarke and marking a major breakthrough in the development of telecommunications. Each satellite, sent into space with a specific orbit and altitude suited to its mission, communicates with Earth via antennas. Its lifespan varies, and it can be decommissioned either by being placed in disposal orbit or by being deorbited and reentering the atmosphere [I.4].

The telecommunications satellite, for its part, is an orbital vehicle which receives terrestrial transmissions (uplink), retransmits them after frequency translation and amplification (downlink) [I.5].

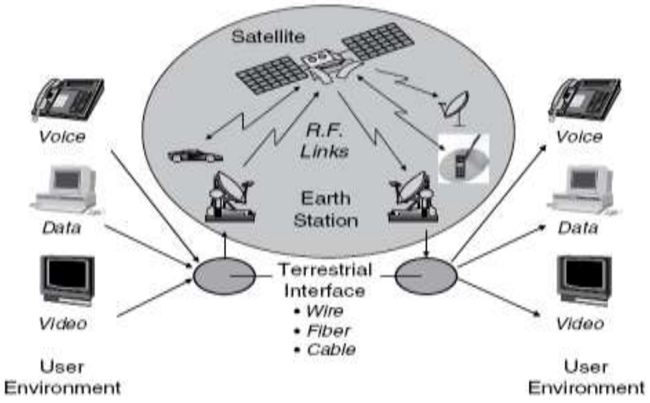


Figure 1:Communications via satellite in the telecommunications infrastructure [I.6].

A communications satellite is also orbiting the Earth. It acts as an active relay for signals transmitted by ground stations. After amplifying them and processing them if necessary, it sends them back to Earth to be picked up by other ground stations. Unlike a stand-alone transmitter, it plays a role similar to relay towers used in terrestrial microwave communications [I.6] .

I.2.1 The advantages of satellites

Satellite communications offer several advantages that are not readily available with alternative transmission modes such as terrestrial microwave networks, cables, or fiber optic networks. Here are some of the benefits of satellite communications [I.6]:

- Distance-independent costs: The cost of satellite transmission is essentially the same regardless of the distance between the transmitting and receiving ground stations. Satellite transmission costs tend to be more stable, especially for international or intercontinental communications over vast distances.

- Fixed broadcast costs: The cost of satellite broadcasting, that is to say the transmission from a transmitting terrestrial terminal to several receiving terrestrial terminals, is independent of the number of receiving terminals of the transmission.

- High capacity: Satellite communications links use high carrier frequencies, with wide information bandwidths. Capacities of typical communications satellites range from a few dozen to a few hundred megabits per second (Mbps), and can provide services for several hundred video channels or several tens of thousands of voice or data links.

- Low error rates: Bit errors on a digital satellite link tend to be random, allowing the use of statistical error detection and correction techniques. Error rates of one bit out of 10^6 bits or better can be routinely achieved efficiently and reliably with standard equipment.

- Diverse User Networks: Large areas of the earth are visible from the typical communications satellite, allowing it to connect many users simultaneously. Satellites are particularly useful for accessing remote areas or communities otherwise inaccessible by terrestrial means. Satellite terminals can be located on land, at sea or in the air, and can be fixed or mobile.

I.2.2. Principle of satellite transmission

Satellite transmission is made up of two main elements:

1. The transmitting station, also called a transmission station, which establishes the uplink between the transmitter and the satellite.
2. The receiving station, also known as the receiving station, which provides the downlink between the satellite and the receiver [I.7].

A satellite telecommunications system consists of two fundamental elements: on the one hand, a terrestrial sector which includes the earth stations and facilitates the connection to terrestrial networks, and on the other hand, a space sector which is made up of the satellites, responsible to ensure the connection between the different stations [I.8].

I.2.2.A Land sector

To establish a link with a satellite, it is essential to have ground equipment which can vary in complexity. These devices constitute what is called a ground station, which is usually connected to user terminals via a ground network, or directly in the case of small stations such as VSATs (very small aperture terminals) and mobile stations. The design of these stations depends on the performance of the satellites, but above all on the quality and availability of the connections they must provide. The cost of ground stations can play a crucial role in a communications network where security, availability and reliability of equipment remain top priorities [I.8].

I.2.2.B Space sector

In the space sector, we find the satellite itself as well as all the control equipment located on the ground, in particular the tracking, telemetry and command stations (TT & C: tracking , telemetry and command), as well as the center satellite control. This center is responsible for all decisions relating to maintaining the satellite in orbit and verifying the proper functioning of its systems as indicated in figure (I.2)[I.8].

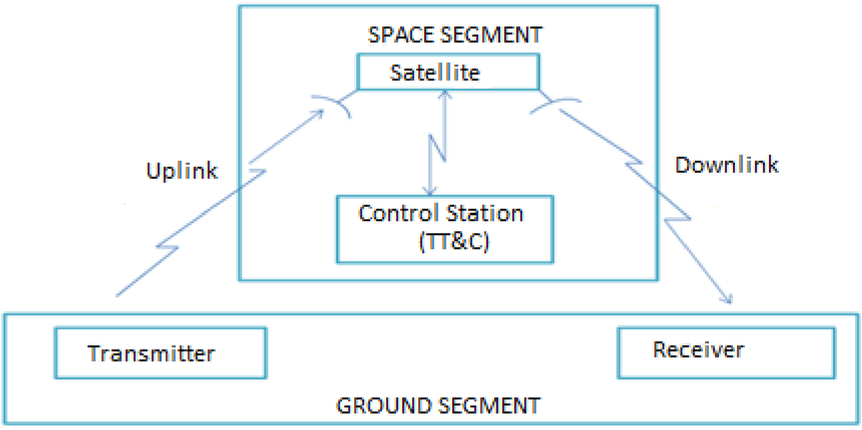


Figure 2:The components of a satellite telecommunications system [I.9]

I.3. Satellite orbit

An orbit represents the regular, repeating path that a space object follows around a more massive body. Orbital configuration plays a crucial role in the design of a satellite network. It determines satellite coverage and variety, as well as physical aspects of propagation such as power constraints and link budgets. Of particular importance is the dynamic topology of the resulting network, as well as the latency and round-trip delay [I.4]. Figure (I.3) allows you to identify the different orbits according to their altitude.

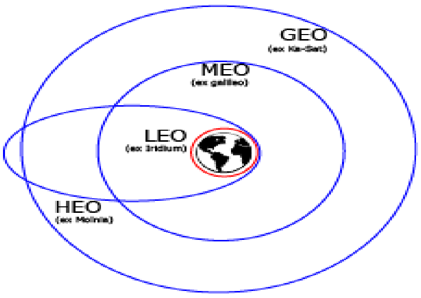


Figure 3:Some examples of orbits in a common hypothetical plane [I.10].

(HEO) – Highly elliptical orbit.

(GEO) - Geostationary orbit.

(MEO) – Medium Earth Orbit.

(LEO) – Low Earth Orbit.

I.3.1. LEO satellite orbit

A low Earth orbit (LEO) is generally a circular orbit located approximately 400 kilometers above the Earth's surface and, therefore, with a period (time to go around the Earth) of approximately 90 minutes. Due to their low altitude, these satellites are only visible within a radius of approximately 1000 kilometers around the sub-satellite point. Additionally, satellites in low Earth orbit quickly change position relative to the position on the ground. Thus, even for local applications, a large number of satellites are required if the mission requires uninterrupted connectivity.

Low Earth orbit satellites are less expensive to launch into orbit than geostationary satellites, and due to their proximity to the ground, they do not need as high a signal strength (recall that signal strength decreases squared of the distance from the source, so the effect is significant). Thus, there is a compromise between the number of satellites and their cost [I.11].

LEO satellites are not always confined to a specific path around Earth in the same way - their orbit may be tilted. This means that there are a variety of trajectories available for LEO satellites. This is one of the reasons why LEO orbit is very commonly used. However, individual LEO satellites are less suitable for telecommunications because they move quickly through the sky, making them more difficult and effort-intensive to track from ground stations [I.12].

I.4. Constellation of satellites

A satellite constellation is a set of artificial satellites that operate in a concerted manner. We can conceive of such a constellation as a set of satellites benefiting from coordinated ground coverage, operating together under shared and synchronized control, so that they effectively overlap in coverage and complement each other, thus avoiding interference with other satellites [I.13].

There are three types of constellations classified according to their orbital altitudes:

- Constellations in Low Orbit (LEO)
- Constellations in Medium Orbit (MEO)
- Geostationary Constellations (GEO)

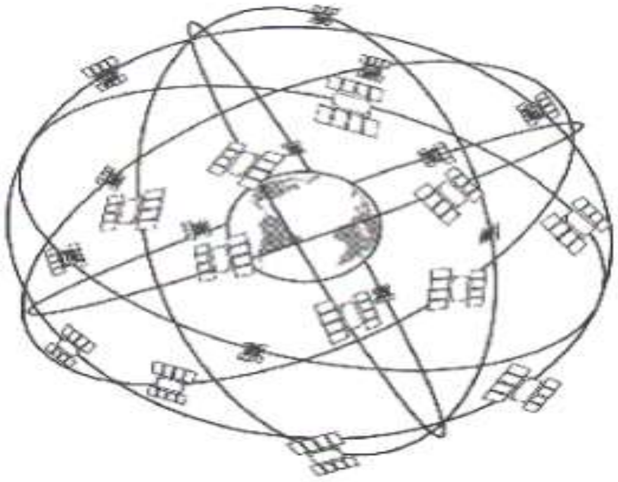


Figure I. 4: A constellation of satellites [I.14].

I.4.1. The constellation of LEO base satellites

The Low Earth Orbit (LEO) satellite constellation refers to a system composed of numerous satellites operating in orbit around the Earth, at altitudes ranging from 500 to 2,000 kilometers. Systems such as Landsat, Skysat and Starlink are widely used in remote sensing and cellular telecommunications due to their global coverage, flexible networking capabilities and short transmission distance between satellites and the ground .

In recent years, the construction and management of mega-constellations has attracted considerable interest from researchers and governments, due to their significant potential to boost economic growth and enhance national security. Traditional LEO remote sensing satellites typically transfer the collected images to a ground data center for centralized analysis. Due to the fast territory dwell time and long review period, the transmission latency of large data sets from LEO satellites to the ground data center is high. It is difficult to effectively support time-sensitive applications such as earthquake assistance. Therefore, the concept of satellite on-orbit computing is proposed. Based on the captured remote sensing images, the analysis task is directly executed on the satellite, and only the results are sent back to the ground, which can significantly reduce the processing time [I.15].

I.4.1.A. Polar constellations

Are those whose orbital plane forms an angle of 90° with the equator, and where the intersection of the orbital planes is located at the poles. Polar orbits provide wide coverage of polar areas, however, as these regions are often desert and sparsely populated, they do not benefit from high demand for use [I.16].

I.4.1.B. The tilted constellations

Are characterized by orbital planes which form an angle with the equatorial plane, very different from 90°. They allow a more efficient distribution of satellites around the Earth [I.16].

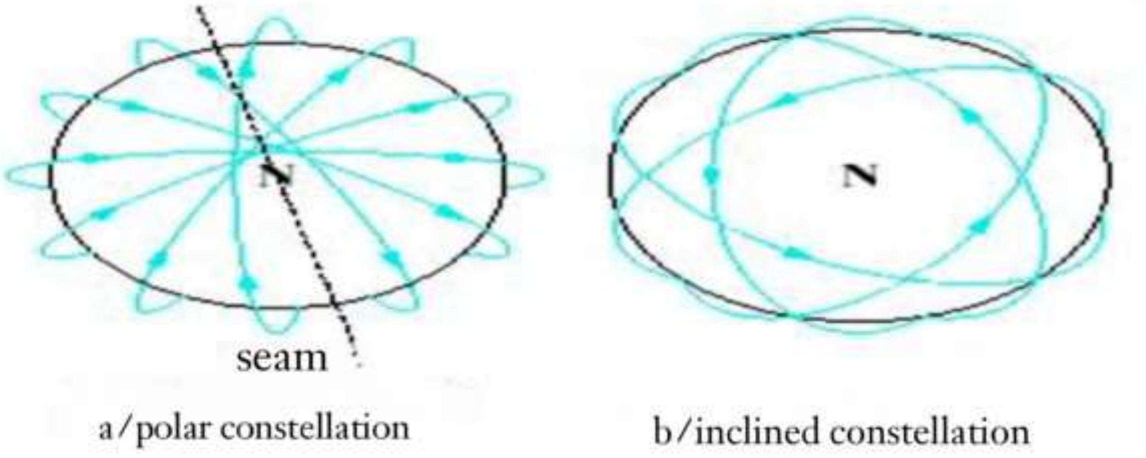


Figure 5:Constellation of satellites [I.16].

I.4.2 Satellite links

Satellite links are generally divided into two types: intra-orbit and inter-orbit. The first type is used to connect two satellites in the same orbit, while the second type is used to connect satellites in adjacent orbits [I.17].

I.5. Parameter of LEO satellites

I.5.1. LEO satellite coordinates (spherical)

Spherical coordinate systems are adopted to represent the position of satellites in low Earth orbit (LEO) due to their arrangement in regularly spaced orbits. These satellites, distributed along orbits, can be characterized by their terrestrial latitude and a fixed longitude. Spherical coordinates use two angular parameters, θ and φ, which correspond to the Earth's latitude and longitude, respectively.

Thus, choosing spherical coordinates for representation offers a practical solution compared to Cartesian or other systems, facilitating calculations and visualization[I.18] . To begin, it is necessary to construct a spherical coordinate system based on the three Cartesian axes .

Figure (I.6) shows the three axes: x, y and z, with the corresponding interpretation of the spherical coordinates represented by the following parameters: r, θ and φ. These parameters describe the coordinates of a point p in three-dimensional space. Their meaning is as follows:

- r : the distance from p to the origin,
- θ : an angle between the z axis and the position vector,
- φ : an angle between the x axis and the projections in the xoy plane of the position vector.

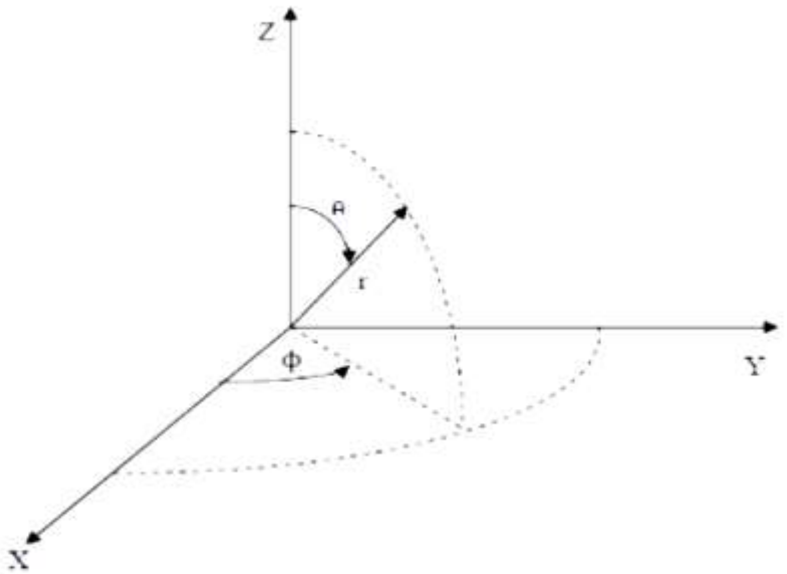


Figure 6:Spherical coordinates on Cartesian axes [I.18]

In some situations it is necessary to obtain Cartesian coordinates from spherical coordinates. The Cartesian coordinate system uses three parameters: x, y and z to represent a point in space. The following equations (I.1) can be used to convert spherical coordinates to Cartesian coordinates .

$$\begin{cases} X = r * \sin(\theta) * \cos(\phi) \\ Y = r * \sin(\theta) * \cos(\phi) \\ Z = r * \cos(\theta) \end{cases} \qquad I.1$$

I.5.2. Satellite rotation speed

The angular rotation of the Earth, calculated according to equation (I-2), amounts to 0.2618 rad/h. It is represented by the formula [I.19] :

$$w_t = \frac{2\pi[\text{rad}]}{24[\text{hours}]} \qquad \text{I}-2$$

The radius of an orbit is calculated by adding the altitude of the satellites to the equatorial radius of the Earth, which is 6378 km. Thus, we obtain R_g =42.178 km and R_1 =7158 km. The relative speed of a LEO satellite with respect to Earth, obtained using equation (I-2), is V_1 =26.804 km/h

$$V_1 = \frac{w_t * R_g{}^{3/2}}{R_1^{1/2}} \qquad \text{I}-3$$

I.5.3. Satellite coverage area

The coverage area A of a satellite is defined by equation (I-4) where R_t represents the radius of the Earth, and θ is the central angle of the Earth [I.16] :

$$A = 2 * R_t^2(1 - cos(\theta)) \qquad \text{I}-4$$

The angle θ is calculated using equation (I-5), where R_e is the radius of the Earth, E is the minimum elevation angle, and $h$is the altitude of the satellite:

$$\theta = \left[cos^{-1} * \left(\frac{R_e * cos(E)}{R_e + h}\right)\right] \qquad \text{I}-5$$

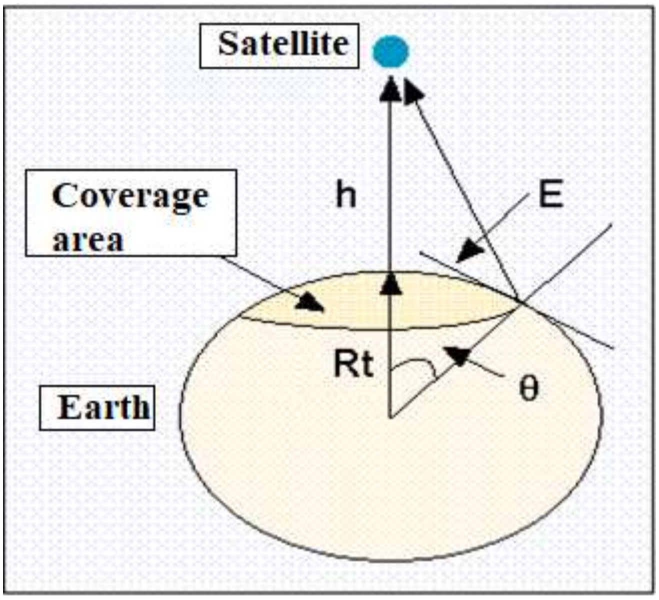


Figure I. 7: Satellite coverage area [I.19].

I.6. Optical intercommunication systems

In this section, we consider a basic diagram of the optical satellite communications segment: the transmitter, the receiver and the tracking system.

I.6.1. Transmitter systems

The transmitter model (Figure I.8) for modulation (OOK) involves the use of a laser transmitter, a telescope and random attenuation mechanisms (such as vibration effects). At the transmitter input, messages are received as electrical signals, which are then converted into optical signals using the laser. The transmitting telescope aligns the laser beam in the direction of the receiving satellite [I.20].

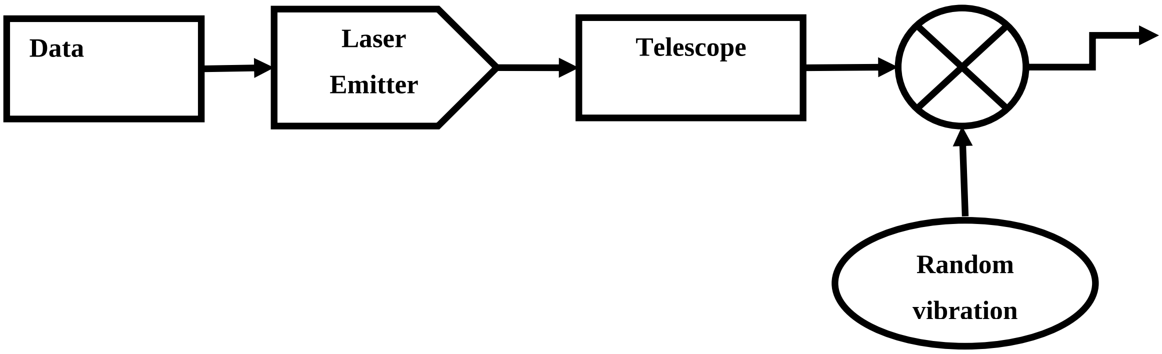


Figure I. 8: Transmitter diagram.

I.6.2 Receiver systems

The receiver model (FigureI.9) for modulation (OOK) has several essential components: a telescope, an optical bandpass filter, insertion losses at the input, an optical amplifier, insertion losses at the output, another optical bandpass filter, a PIN photodiode, an electrical filter and a decision circuit.

The receiving telescope focuses the received radiation onto the optical filter, which blocks most of the background radiation to prevent interference with subsequent components. The signal then passes through the optical amplifier, which suffers losses due to reflections and optical mismatches. The amplifier output is an amplified version of the input signal, but with optical amplifier noise.

The optical filter at the amplifier output attenuates part of the amplifier noise, then the radiation is converted into an electrical signal by a photodiode. This electrical signal is then filtered by an electrical filter.

Based on the amplitude of the electrical signal and its arrival time, the decision circuit determines the type of information received [I.20].

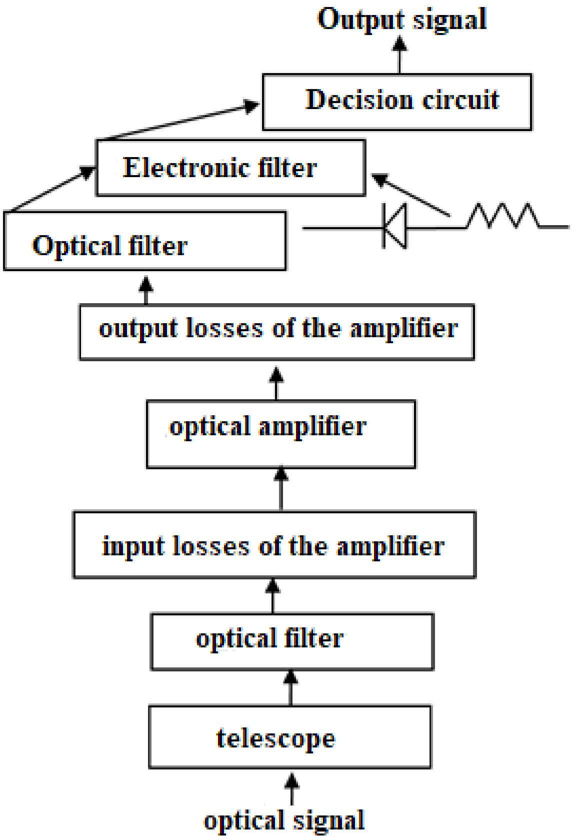


Figure I.9 9Receiver diagram

I.6.3. Tracking systems

To establish optical communication between two satellites, it is necessary to continuously align the line of sight of their optics throughout the duration of the communication. To meet this requirement, satellites use ephemeris data (the position of the satellite according to the orbit equation) for approximate pointing, and a tracking system for precise pointing to the other satellite. The most common method of tracking between satellites includes the use of a beacon signal on one satellite and a quadrant detector with a tracking system on the other satellite. [I.21] The precise elevation and azimuth angles of the pointing system estimate the pointing direction from the output signal of the quadrant detector. In Figure (I.10) we can observe the main components of the tracking system. Radiation from the beacon on one satellite is received by the telescope on the other satellite. The telescope focuses the received radiation on the quadrant detector.

The pointing and control unit calculates the pointing direction of the telescope according to the signal from the qu adrant detector [I.20].

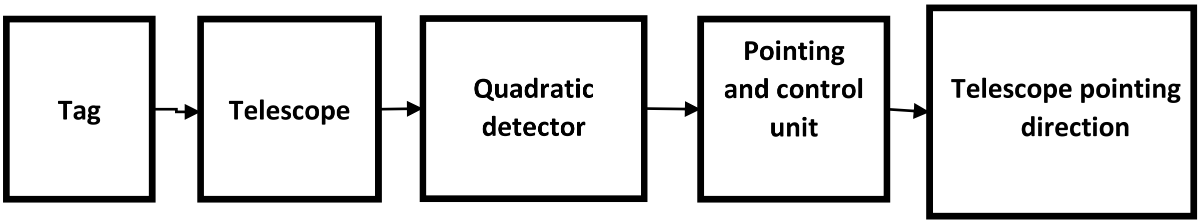


Figure I. 10: Diagram of the monitoring system

I.7. Standard transmission structure in satellite networks

Figure (I.11) represents the standard structure of a digital transmission system in laser satellite networks.

The standard configuration of a digital transmission system in laser satellite networks includes several essential elements:

- A light source, usually a laser diode, coupled to a modulator. This combination is used to transmit information on a light wave. Intensity modulation is used to encode this information.
- When using a technique called WDM (Wavelength Division Multiplexing), where several channels of data are transmitted simultaneously over the same optical fiber, each channel requires its own light source and modulator.
- A multiplexer is necessary in a WDM system to bring together the different data channels in the optical frequency band before sending them through the optical fiber.
- To ensure that the signal remains strong and clear over long distances, a power amplifier is used to increase the power of the optical signal before it is injected into the optical fiber.
- In-line amplifiers are also placed along the fiber to compensate for the signal attenuation that naturally occurs when it travels long distances. The distance between these amplifiers, called the "amplification pitch", is a crucial characteristic of the link.
- An optical preamplifier is used at the receiving end to boost the optical signal before it is converted into an electrical signal.
- In the case of a WDM system, a demultiplexer is used to separate the different data channels on reception.

- For each data channel, a photoreceiver is used to convert the optical signal into an electrical signal, which can then be sampled and processed to extract the transmitted information [I.22].

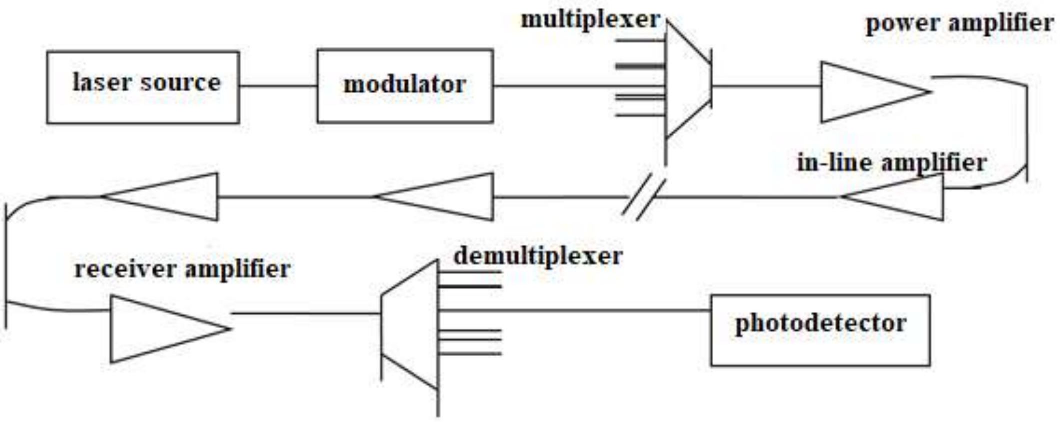


Figure I. 11: Transmission structure in Satellite networks.

I.7.1. Noise in photodiodes

Optical detector plays a crucial role in optical transmission systems due to its strict performance requirements to ensure compatibility. It is essential to understand the origins, characteristics and effects of different types of noise in order to evaluate and specify the operating characteristics of optical telecommunications systems.

There figure (I.12) represents THE different noises whichhappen during of there detection And of the amplification of signal.

Fundamental noise, generally important in open-air communications, becomes negligible in guided transmissions if the guidance starts near the source and the guide is impervious to external interference.

Beat noise arises in the detector due to different spectral components of the signal carrier. Quantum noise, dark current noise, and surface leakage current noise are all types of granular noise, characterized by a Poisson statistic.

Quantum noise, coming from intrinsic fluctuations in the production of electron-hole pairs in the photodiode, is a fundamental element. In non-avalanche photodiodes, thermal noise, generated by the load resistance of the detector and the active components of the electronic amplifier, predominates.

Avalanche amplification in a photodiode introduces additional noise, called excess noise, into the receiver.

This noise increases the granular noise above its primary level, prior to avalanche amplification. Despite this, avalanche photodiodes provide a clear improvement to direct detection optical systems [I.23].

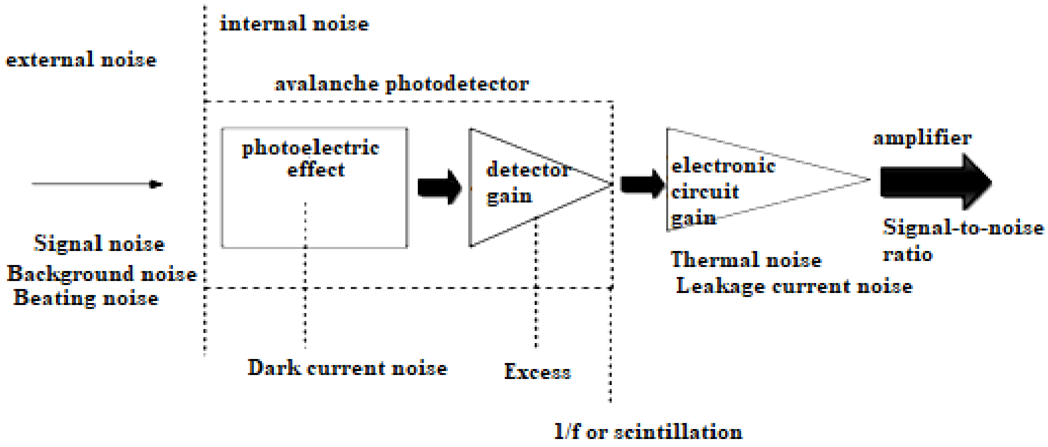


Figure 12:Diagram of the different noises that appear during detection [I.23].

I.7.2. Optical amplification

Amplification plays a crucial role in optical transmission, and over the past three decades, considerable attention has been paid to optical amplifier research. Although solid-state amplifiers have been studied since the 1970s, their development as integrated amplifiers in transmission systems has remained limited, with only a few demonstrations in the 1.3 µm window, where fiber amplifiers doped are not commercially available. However, their characteristics make them very useful in various fields, notably optical signal processing (multiplexing and demultiplexing), where non-linear effects are exploited.

The doped fiber amplifier, which appeared at the end of the 1980s, quickly became a major industrial component in optical telecommunications networks. Its reliability and its characteristics, such as its linearity (which makes it insensitive to variations in average signal power) and its low noise level close to theoretical limits, make it a crucial element of modern optical networks.

On the one hand, the optical amplifier makes it possible to overcome the limitations due to fiber attenuation by considerably increasing the power of the signal online and allowing its re-amplification during propagation. However, this can result in the addition of noise, thus leading to the notion of an amplified system, essential for wavelength division multiplexing techniques. In-line amplifiers thus replace intermediate repeater-regenerators.

On the other hand, used as a preamplifier, the optical amplifier significantly improves the sensitivity of the photoreceptors, thus overcoming the limitations imposed by thermal noise. This property has diminished the interest in research on reception. However, injecting high levels of power into fibers can cause non-linear effects, which can be a source of additional degradation but can also be exploited beneficially [I.24].

I.7.3. Physical principle of laser operation

The acronym LASER stands for "Light Amplification by Stimulated Emission of Radiation". A laser is a device that produces coherent radiation in the infrared, visible and ultraviolet regions of the electromagnetic spectrum. To make a laser, three essential ingredients are necessary: an active medium, a pumping mechanism and an optical resonator

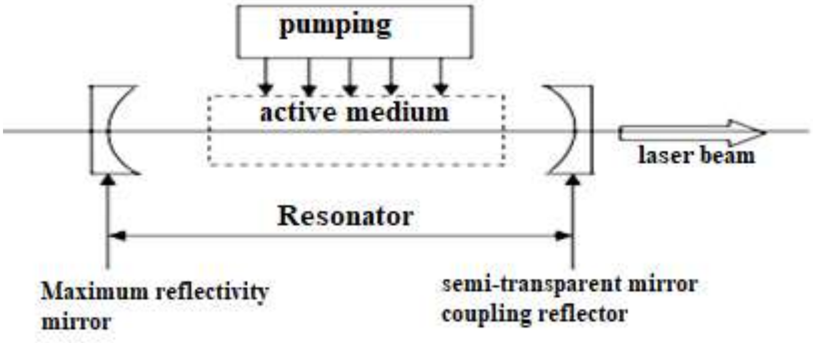


Figure 13 : Principle diagram of a laser [I.22]

A laser system includes three main components:

The active medium composed of the atoms to be excited, which can be solid, liquid or gaseous;

A pumping source which provides the energy necessary to excite the atoms of the active medium, which may be electrical or luminous;

The resonator is a cavity formed by two mirrors, one fully reflective and the other semi-transparent. This resonator confines and amplifies the light emitted by the active medium, thus promoting oscillation and the production of a coherent and directional laser beam thanks to optical feedback.

Population inversion favors stimulated emission in the active medium of a laser, where a photon is more likely to cause the de-excitation of an excited atom than to be absorbed by an atom at the lower level. This results in increased production of photons by stimulated emission compared to absorption processes. This chain reaction allows photons to multiply in the active medium, thus contributing to the amplification of light in the laser. However, this process alone is not sufficient to generate a laser beam, hence the use of an optical resonator. This resonator, made up of two parallel mirrors, allows light to pass through the active medium several times, thus promoting the stimulated emission of additional photons and creating a coherent and directional laser beam [I.25].

I.7.4. Developed structure of a transmission system

Due to the continuous vibrations of the laser beam emitted in laser satellite networks, several improvements have been made to their standard structures in order to reduce the effects of these vibrations and improve the quality of communication.

Figures (I.8) and (I.9) describe the structures developed for the transmitter and receiver in laser satellite networks.

The receiver model (I.9) is composed of a telescope, an optical bandpass filter, an optical amplifier, another optical bandpass filter, a photodiode (PIN), an electric amplifier, an electric filter and a decision circuit.

The transmitter model (I.8) includes a laser transmitter, a phased element telescope (telescope phased array), a control unit and a random vibration generator.

When the message reaches the transmitter input, it converts the electrical signal into an optical signal using the laser. Then, the transmitting telescope directs the laser radiation towards the direction of the receiving satellite. The control unit adjusts the gain of the transmitting telescope based on the amplitudes of random vibrations, thereby reducing the effects of these vibrations and improving the quality of communication.

The receiving telescope focuses the radiation sent by the transmitter towards an optical filter. This optical filter prevents a large amount of shot noise from entering the next stage of the receiver. After filtering, the optical signal is amplified by an optical amplifier located at the output of the optical filter. This amplifier adds thermal noise to the amplified signal, a large part of which is eliminated by an optical filter located at the output of the optical amplifier.

After filtering, the optical signal is converted by a photodiode into an electrical signal. This signal is then amplified by an electrical amplifier before undergoing another filtering operation by an electronic filter in order to remove part of the thermal noise created by the electrical amplifier. Finally, the decision circuit determines, depending on the amplitude of the electrical signal obtained, the type of bit received, 1 or 0 [I.26].

I.8. FSO (free space optical) technology

Free-space optical (FSO) communications technology relies on the use of lasers to establish optical broadband connections under line-of-sight conditions. Currently, it enables speeds of up to 2.5 Gbps for data, voice and video, without requiring fiber optic cables or frequency authorizations. To operate, FSO uses light, which can be directed by light-emitting diodes (LEDs) or lasers. This method, similar to that of optical transmissions via optical fiber, exploits the higher speed of propagation of light in air compared to glass. FSO technology relies on units comprising an optical transceiver equipped with a laser transmitter and receiver to enable full two-way communication. Each FSO unit also includes a lens for transmitting light and a receiving lens connected to a highly sensitive receiver via an optical fiber. Its deployment requires no spectrum licenses and its ease of upgrade and open interfaces enable the integration of equipment from a variety of vendors, providing service providers with flexibility to invest in their telecommunications infrastructure [I.27]

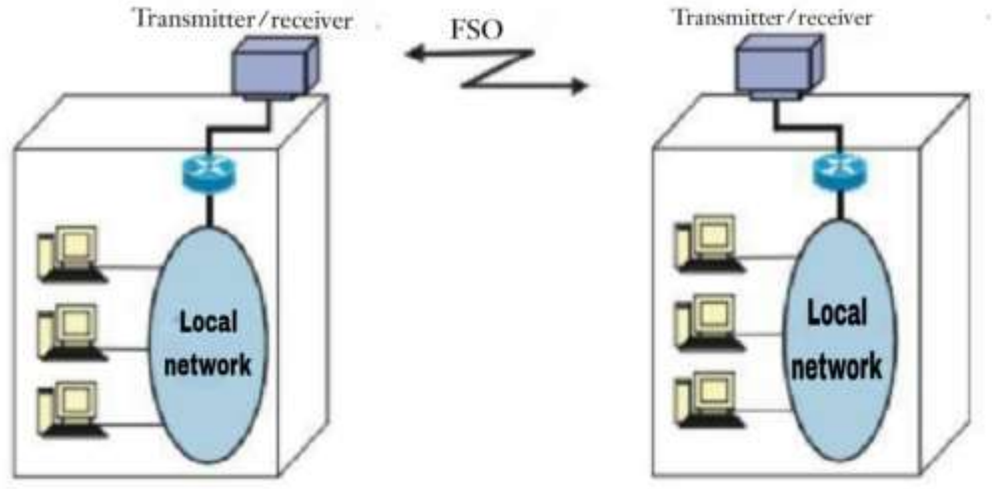


Figure 14:Structure of an FSO link used to connect two local networks [I.28]

I.9. OWC technology (optical wireless communication)

Wireless technologies have been one of the great successes in technological history, fulfilling humans' dream of communicating from anywhere and at any time. While voice communication was the primary service a decade ago, wireless data and mobile Internet have spread much faster than anyone could have imagined, enriching the voice communication experience with a much richer multimedia content. Wireless devices, applications and services have already radically changed the way we live, work and socialize. The emerging concept of the Internet of Things further promises wireless connectivity between machines, sensors and virtually all objects in the environment, thereby realizing ubiquitous communication between machines and between machines and humans. This would further change our interaction with the physical world and make wireless communication an integral part of human life. [I.29]

Optical Wireless Communication (OWC), also known as wireless optics, is positioned as a promising technology that does not currently require an operating license. It mainly uses three bands of light: near infrared, visible and ultraviolet in the UV-C band. Discovered since the 1970s, OWC gained renewed interest in the 2000s thanks to advances in white LEDs, providing rapid switching capabilities for communication. Its advantage lies in the absence of interference with existing RF systems and VLC allows combined use of illumination and communication. Additionally, because optical waves are more difficult to jam or intercept than RF waves in indoor environments, OWC connections face varying challenges depending on the frequency band used, environment and distance [I .30].

Figure 15:Examples of OWC applications according to scope [I.30]

I.9.1. Structure of an OWC optical communication system

I.9.1.A. Optical transmitter

The optical transmitter is a complex device composed of several elements, such as a light source and a modulator. Its main role is to generate an optical signal carrying the data to be transmitted on the transmission medium. Basically, it converts electrical signals into light pulses.

Optical transmitters must meet several essential criteria:

- Efficient operation at room temperature.
- Ability to modulate light emitted at high frequencies.
- Significant optical power emission.
- Long operational life.

In other words, an optical transmitter must be able to operate under normal ambient conditions, rapidly modulate the emitted light, produce sufficient optical power, and have an extended lifespan.[I.31].

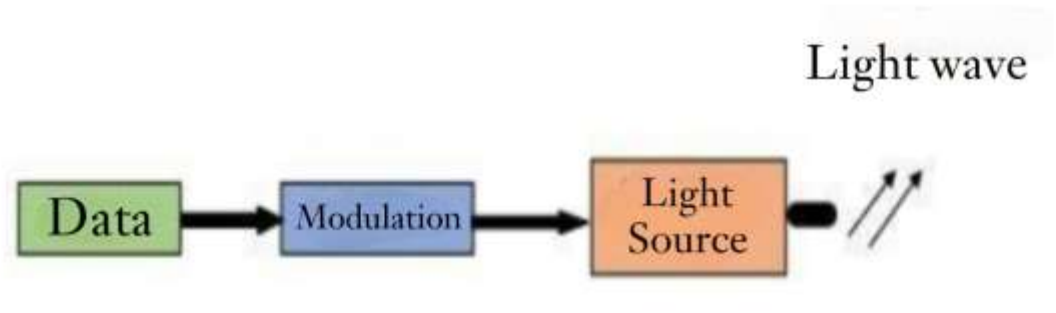


Figure I. 16: Synoptic diagram of the OWC transmitter block [I.31].

I.9.1.B. Light-emitting diodes (LEDs)

Light-emitting diodes (LEDs) are semiconductor devices that emit light. Because their transmit power is relatively low, they are mainly used in short-range applications with moderate spectral requirements, typically up to 155 Mbps [I.32]. This includes applications such as Indoor Wireless Optical Communications (IWOC).

One of the main advantages of LED sources is their extremely long lifespan and low cost[I.33].

I.9.1.C. Laser diodes

A laser diode is an optoelectronic component made from semiconductor materials that manipulates light by exploiting three essential processes: absorption, spontaneous emission and stimulated emission. Unlike other light sources, the laser diode produces a coherent, monochromatic beam, making it a preferred tool in very long distance transmission systems. In addition, laser diodes are distinguished by their low spectral width.

They are widely employed in free space optical communications due to their high frequencies, thus allowing higher modulation rates, and their ability to cover greater distances with their beam [I.34].

In the transmitting part of a system, there are also two types of modulation: intensity modulation and external modulation.

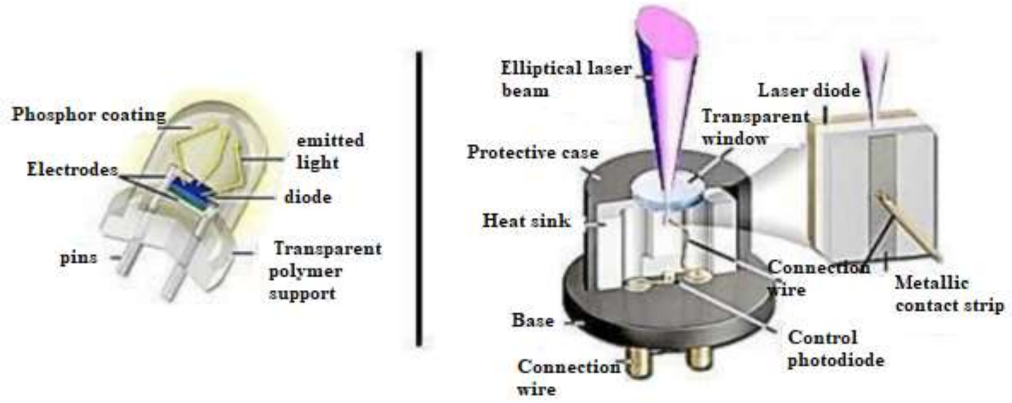


Figure 17:Architecture of an LED and Structure of a laser diode [I.34].

In the transmitting part of a system, there are also two types of modulation: intensity modulation and external modulation.

I.9.1.D. Intensity modulation (IM: Intensity Modulation)

This modulation method involves the transmission of information based on the instantaneous power of the carrier signal. This can be achieved by directly varying the driving current of the optical source in synchronization with the data to be transmitted. The fundamental principle of direct modulation transmission is illustrated in figure (I.18) [I.35].

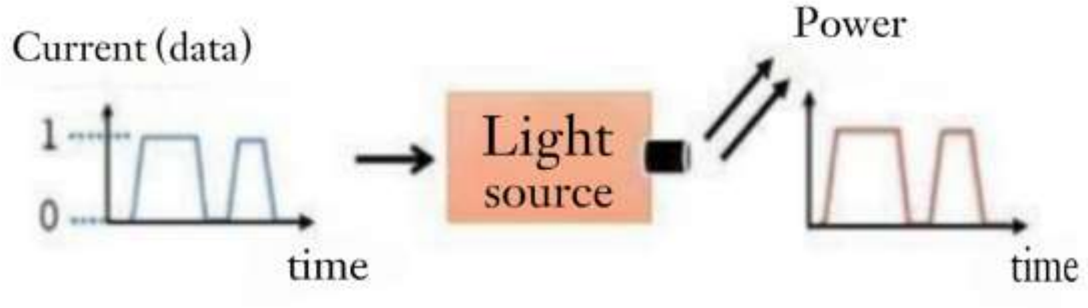


Figure I. 18: Basic principle of direct modulation [I.35].

I.9.1.E External modulation

External modulation is carried out by modulating the light beam at the output of the laser, which operates in direct current, rather than modulating the laser supply current. This approach makes it possible to reduce the impact of the chirp phenomenon on the transmitted optical signal. The following figure illustrates the external modulation diagram.[I.36].

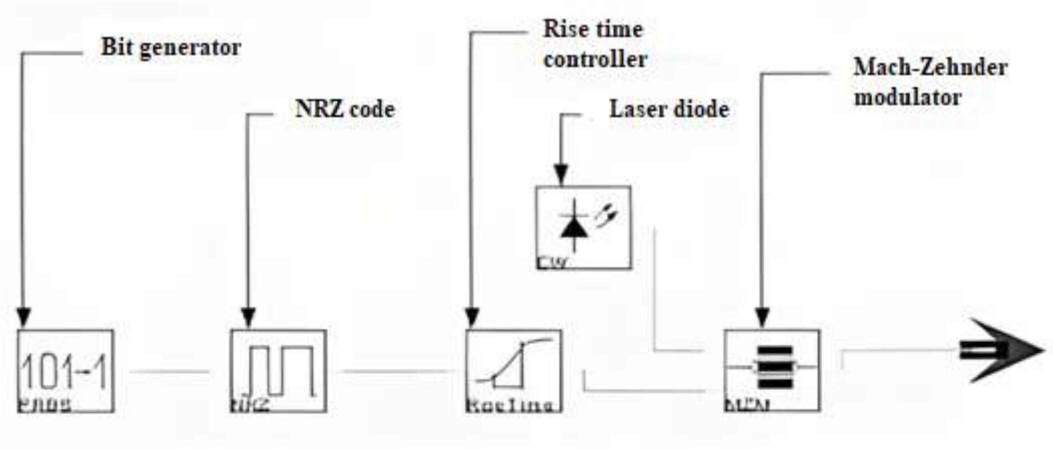


Figure 19:External modulation diagram [I.36].

In optical communications systems, various types of modulators are used, including Mach-Zehnder modulator and electro-absorption modulator. These are the two types of optical modulators most commonly used in optical transmission systems [I.36].

In the same way as for transmitting modules, the interface of a receiving module is responsible for transforming the light signal into an electrical signal while minimizing signal degradation. This function is provided by the photodetector, which acts both as a photon counter and as a current generator. Photodetectors are selected based on several criteria, including their sensitivity to the wavelength used, their speed and their ability to minimize noise. To meet these requirements, semiconductor photodetectors are often favored due to their speed and ease of use [I.37].

The photodetector, typically a reverse biased PN junction, converts the received optical signal (the photons) into an electrical signal via the photoelectric effect.

Photodiodes can be categorized into two types: those without internal gain, such as PN and PIN photodiodes, and those with internal gain, such as avalanche photodiodes (ODA)[I.37].

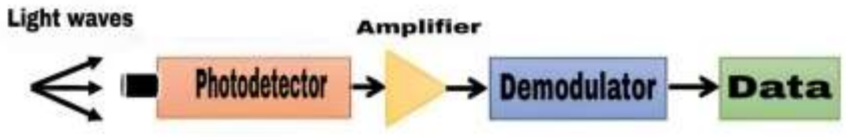


Figure I. 20: Block diagram of the optical receiver [I.37].

I.9.1.F Transmission channel

Communication links (OWC) use the atmospheric environment as a transmission channel, which can cause various constraints due to the complex and changing nature of this environment. The characteristics of the emitted laser beam may be altered due to this atmospheric complexity. OWC links face significant challenges due to the spatio-temporal variability of the physical properties of the atmosphere and the diversity of its components.

Atmospheric attenuation is one of the main challenges, limiting the effective range of the link. This attenuation is the result of various selective phenomena depending on the wavelength. These phenomena include molecular absorption, which exhibits strong spectral dependence, molecular scattering (known as Rayleigh scattering), attenuation due to suspended particles such as aerosols, and precipitation such as rain and snow. Additionally, atmospheric turbulence, resulting from spatio-temporal fluctuations in the refractive index of air, also contributes to attenuation and introduces phenomena such as flickers and spatial fluctuations of the beam [I.38].

I.9.2 Applications of OWC

OWC (Optical Wireless Communication) has a wide range of potential applications, such as smart cities and homes, railway stations, airports, data centers, healthcare, manufacturing plants, communication underwater, etc. It is particularly promising in environments sensitive or restricted to RF signals, such as hospitals or petrochemical plants, and can also be used for military submarine communications due to secure data exchange [I.39] .

Applications of OWC can be classified based on transmission ranges, including ultra-short range, short range, medium range, long range and ultra-long range. Here are some examples :

1. Ultra-short range applications:
    - Optical Interconnects (FSOI): Used for chip-to-chip communications due to their high throughput, low latency, and high flexibility compared to copper-based alternatives.

2. Short Range Applications :
    - Wireless Body Area Networks (WBAN) and Wireless Personal Area Networks (WPAN): Used to monitor health parameters in hospitals using visible light (VL) based sensors.

- Optical Camera Communications (OCC): Uses a camera as an optical receiver to establish machine-to-machine (M2M) communications.

3. Medium Range Applications:
    - Wireless Local Area Networks (WLAN): Used for wireless communications over a few meters.
    - Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications: Use car LEDs to communicate with nearby vehicles.
4. Long Range Applications:
    - Free Space Optics (FSO): Used for high-speed point-to-point communications over several hundred meters to several kilometers.
5. Ultra-Long Range Applications:
    - Satellite-to-Satellite Communications: Use FSO links for communications over thousands of kilometers, providing high spectral efficiency.

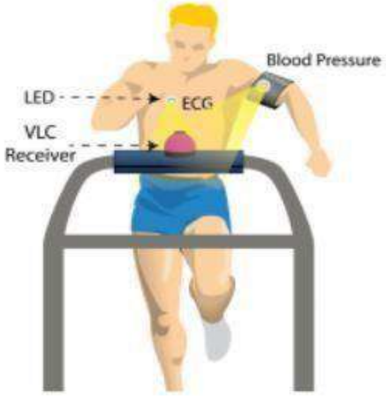


Figure I. 21: Optical WBAN in free space: biomedical application measures cardiostress (OWC short-range applications) [I-40].

I.9.3. The advantages and disadvantages of OWC

The transition to Optical Wireless Communication (OWC) opens the way to a series of revolutionary benefits in the field of space communications including:

1. Unlicensed Spectrum: OWC uses unlicensed and unregulated spectrum, unlike RF spectrum, which is regulated by the ITU and often congested.
2. High data throughput: OWC systems offer potentially higher throughputs than RF technologies due to their ultra-wide bandwidth of 400 THz .

3. Secure Transmission: Light signals from OWC systems cannot pass through walls and obstacles, providing more secure transmission than RF signals.
4. No Interference with RF Signals: The light signals of OWC systems do not interfere with RF signals, making them suitable for environments sensitive or restricted to RF signals, such as hospitals and aerospace platforms.
5. Ease of implementation: OWC systems are easy to implement through the use of commercially available components, including LEDs for light communications.
6. Energy Efficiency: LEDs, widely used for lighting, can also serve as transmitters in OWC systems, providing higher energy efficiency than other light sources.
7. Safety for human health: The LEDs used in OWC systems comply with safety regulations for skin and eyes, ensuring the safety of human health.
8. Reduced Cost: OWC system equipment is inexpensive compared to RF wireless technologies, providing significant savings.

However, despite its many advantages, Opitical Wireless Communication (OWC) is not free from challenges and disadvantages that should be taken into consideration such as:

1. Channel Effects: OWC systems are sensitive to optical channel effects, such as obstacle attenuation, noise, and multipath propagation .
2. Obstacle Sensitivity: Obstacles between the transmitter and receiver can block transmission, especially in case of line-of-sight (LoS) communication.
3. Eye safety: Regulatory standards place limits on optical power to ensure eye safety, which can limit the performance of narrow beam links.
4. Signal modulation: Choosing a suitable modulation scheme is crucial to address channel effects, energy efficiency and spectral efficiency [I.39].

I.10. Conclusion

In conclusion, satellites using laser technology for intercommunication are a decisive step towards faster and more reliable global connectivity. These present a promising solution for the growing needs in terms of data transfers and communication services, both in the terrestrial and space context. The potential impact of these laser satellites is considerable, as they can help improve the quality of human life while facilitating the exploration and sustainable use of our planet. The prospect of a future where spatial connectivity would be accessible and efficient now seems more realistic thanks to these technological innovations .

Chapter 2: Big data transmission techniques by Laser

II - 1 . Introduction

With the proliferation of data from various sources such as models, on-site observations, and particularly satellites, daily access to an additional 300 GB of satellite data has become the norm. These data require careful analysis to extract relevant information, leading to an increasing use of data mining methods [II.1].

This abundance of information, referred to as " Big Data ", has forced computer scientists to design new concepts and innovative processing methods. These advances are grouped under the name “Big Data” or “Massive Data” [II.2].

The second chapter of our study focuses on massive data transmissions (Big Data) and the calculation of the link budget . In this chapter we will address the fundamental principle of data transmissions, the importance of setting solid specifications for these transmissions, as well as the analysis of the calculation of the link budget through a specific case study. This section will be essential for understanding the technical foundations and practical requirements necessary for the successful implementation of Big Data transmissions.

II-2. Big Data

II-2-1. History on Big Data

Since the 1990s, the term "Big Data" has been commonly used, although its precise origins remain obscure. John R. Mashey , of Silicon Graphics, is often cited as helping to popularize it. Researchers have long explored data analysis techniques to inform decision-making. The total amount of data in the world has increased significantly, from 4.4 zettabytes in 2013 to 44 zettabytes in 2020 [II.3].

In recent years, the volume of digital data generated around the world has seen explosive growth, from 2 zettabytes in 2010 to 64 zettabytes in 2020. Forecasts suggest continued growth, with an estimate of more than 180 zettabytes of data generated worldwide. here 2025. This increase is stimulated by the democratization of connected objects and the deployment of 5G technology [II.4].

Big Data is transforming the way we perceive the world and redefining what is considered a source of economic value. This profound transformation influences how data is used to guide strategic decisions and generate valuable insights [II.5] .

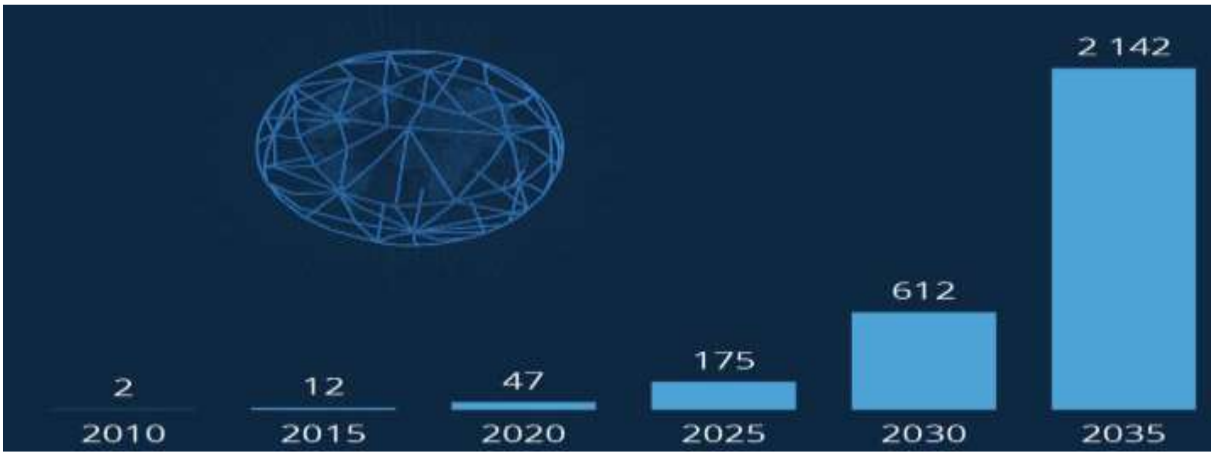


Figure II. 1: Annual volume of digital data created globally since 2010 in zettabytes [II.4]

II -2-2. Definition of Big Data

From a literary point of view, the term "Big Data" refers to massive data sets, also called "big data." It is an English expression used to describe large amounts of data that cannot be managed effectively with traditional database management tools. As a result, these data pose challenges in terms of processing, storage, analysis and management, which cannot be solved with traditional methods [II.6].

The concept of "Big Data" has been defined in different ways, but no definition has been universally accepted due to its complexity. The definition of this concept varies depending on the users and service providers who are interested in it.

Among the various definitions, we can consider that:

Big Data are massive sets of information, characterized by their large volume, high velocity and wide variety. They require innovative and cost-effective methods of processing information to improve understanding and decision-making [II.7].

Big Data represents a set of technologies, architectures and procedures designed to analyze and process large quantities of heterogeneous data, in order to extract relevant information at a reasonable cost [II.8].

II -2-3. Type of Big Data data

In the context of Big Data, data collected, curated and analyzed comes from various domains and is generated by multiple heterogeneous data sources. This diversity results in a dataset comprising different types, including both structured, unstructured and semi-structured data [II.9].

II -2-3-A. Structured data

Structured data is characterized by a defined format and length, making it easier to store, analyze and organize. They are organized in a recognizable structure, which allows queries to be efficiently answered to retrieve information within an organizational framework. A typical example of structured data is a relational database using structured query language (SQL). These databases contain numbers, dates, character strings (text) and other elements organized in a logical manner, which simplifies their management and manipulation for various purposes [II.10].

II -2-3-B. Unstructured data

Unstructured data consists of information presented in various forms, which do not conform to conventional data models. They are generally not suitable for organizing in a traditional relational database. As a result, processing and analyzing unstructured data often proves difficult and time-consuming [II.10].

According to Feldman and Sanger, unstructured data is defined by the lack of defined structure. They typically include items such as bitmap images, text, emails, and other types of data that do not fit into a conventional database structure [II.11].

II -2-3-C. Semi-structured data

Semi-structured data is data that has some irregularity, may be incomplete, and has a structure that may change quickly or unpredictably . Although they do not follow a fixed or explicit pattern, they can nevertheless have related but different properties between them.

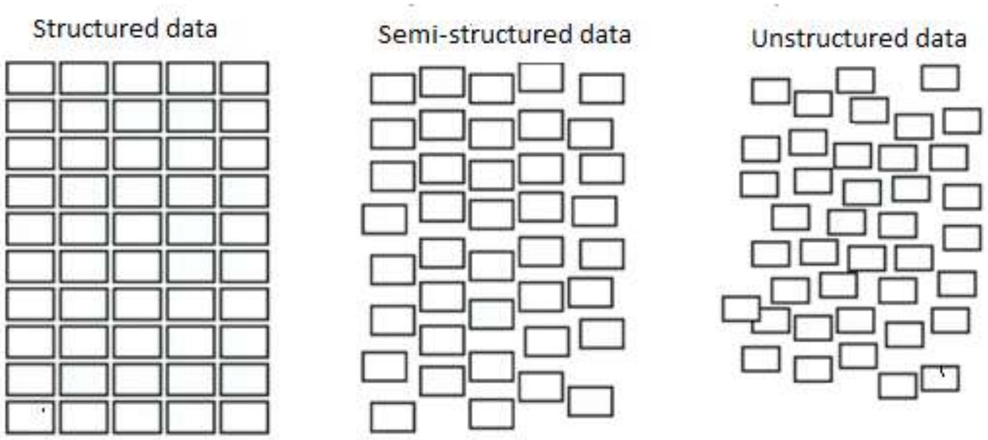


Figure II. 2:Type of Big Data data [II.12]

According to Hanig , Schierle and Trabold , the semi-structured data model allows information from different sources to be grouped into a coherent whole. For example, this may include email files, XML documents, and other file types where the data structure may vary but remain interconnected [II.12].

II -2-4 Characteristics of Big Data

- **Volume** : The volume or size of data now exceeds terabytes and petabytes due to the large number of technological devices we use today. The sheer scale and growth of data is outpacing traditional methods of storage and analysis [II.13].
- **Speed** : Speed is a crucial characteristic of Big Data, denoting how quickly the data is generated. For example, a high speed of generating data results leads to the rapid accumulation of large amounts of data in a short time [II.14].
- **Variety** : the data to be processed includes various formats, whether structured or unstructured: databases, texts, sensor data, audio files, videos, trajectories, log files, and others [II.15].

- **Veracity** : Veracity refers to the accuracy and reliability of data. To fully realize the value of data, it is necessary to clean it to remove noise. This data cleaning process is of great importance to filter out incorrect and faulty data [II.16].
- **Value** : the value of data refers to its usefulness according to the objectives sought. The ultimate goal of any big data analytics system is to extract this value from the data. The value of data is closely linked to its veracity or accuracy. For some applications this value also depends on the speed at which we can process the data [II.14].

Figure II. 3:5Vof Big data [II.18]

II -2-5 How Big Data Works

To effectively exploit Big Data while respecting the five main aspects, the process is broken down into four essential steps:

1. Data collection: Use of software solutions or connected terminals to gather data.
2. Data processing: Initial grouping in batches for ease of subsequent manipulation.
3. Data cleaning: Elimination of irrelevant data and correction of errors or incorrect information to ensure data quality.
4. Data Analysis: Initial exploration to discover relationships and patterns, followed by the use of predictive tools and artificial intelligence for deeper analysis.

These steps transform disparate data sets into understandable and actionable insights. The exploitation of Big Data is of crucial importance for organizations, because it contains major potential for discoveries and opportunities [II.1].

II -3. Connection assessment

The link budget, also called Link budget in English, is an essential element in determining the power levels necessary in a transmission channel. It encompasses all the equations necessary to calculate the signal-to-noise ratio at the receiver output, taking into account all parameters affecting the power of the transmitted wave.

Thus, there are two separate link budgets, each with parameters such as G/TB, figure of merit and EIRP. Powers and antenna types can vary considerably from station to station. We also took into account certain performance criteria of channel access protocols and their influence on the quality of the satellite link [II.19].

II -3-1. general settings

II -3-1-A. The signal-to-noise ratio (C/N)

The signal-to-noise ratio (SNR) expressed in decibels per Hertz [dB Hz], called C/N0, represents the relationship between the power of the carrier signal and the power density of the noise over the passband. This results in dividing the power of the noise by the bandwidth of its power spectral density [II.20]

$$\frac{\mathrm{S}}{\mathrm{B}} = \frac{P_s}{P_B} \qquad \mathrm{II}-1$$

$$\frac{S}{B} = (\frac{U_S}{U_B})^2 \qquad \mathrm{II}-2$$

$$\frac{S}{B_{db}} = 10log\left(\frac{S}{B}\right) \qquad \mathrm{II}-3$$

II -3-1-B. The ratio of energy per bit to noise (E/N)

E $_b$ /N $_0$ represents the ratio between the energy per bit and the power spectral density of the noise. It is used to evaluate and compare the bit error rates (BER) of digital modulation systems. These two parameters are normalized, thus eliminating the dependence on bandwidth [II.20]

$$\frac{C}{N_0} = \frac{E_b}{N_0} * R \qquad \mathrm{II}-4$$

$$\left(\frac{C}{N_0}\right)_{dB} = \left(\frac{E_b}{N_0}\right)_{dB} + 10 * \log(R) \qquad \mathrm{II}-5$$

R: is the actual rate of information bits.

II -3-1-C. Propagation loss ($\boldsymbol{P}$)

The propagation loss represents the comparison between the equivalent isotropic radiated power by the transmitter and the power available at the output of an isotropic receiving antenna [II.21]

$$AP = AEL - L_{fs}(dB) \qquad \mathrm{II}-6$$

The calculation of the antenna gain takes into consideration the effect of the local ground near the antenna, while that of the transmission loss does not take this effect into account.

II -3-1-D. Free Space Attenuation (AEL)

When electromagnetic waves propagate, they disperse in space, resulting in attenuation even in the absence of losses in the medium. In the low frequency bands, below 10 GHz, losses due to weather phenomena such as rain are minimal. To quickly estimate the attenuation levels on the receiver side when the two stations are in direct line of sight, one can use equation (II.7) which expresses attenuation as a function of distance and frequency.

$$A = 10 * log\left(\frac{4\pi d}{\lambda}\right)^2 \qquad \mathrm{II}-7$$

With: A: free space attenuation between isotropic antennas, expressed in dB.

d: distance between transmitter and receiver expressed in meters

λ : wavelength of the radiation, expressed in meters [II.20]

II -3-1-E. Free space attenuation (fs)

Free space attenuation can be attributed to several factors, including:

- Absorption loss, resulting from absorption by the ionosphere, atmospheric gases or precipitation.
- Diffraction attenuation, such as that observed in the case of ground waves.
- Attenuation due to equivalent reflection or scattering, as occurs in the ionosphere, accounting for focusing or devocalization effects due to the curvature of a reflecting layer.
- Polarization coupling loss, resulting from any polarization mismatch between the antennas for the path considered.
- The reduction in antenna gain or degradation of antenna gain, which may be due to the presence of significant scattering phenomena along the path.
- Interference between direct radiation and rays reflected by the ground, obstacles or atmospheric layers.

These elements contribute to the decrease in signal power as it propagates through free space [II.20].

II -3-2. The Gain of an antenna

The ratio between the power P $_r$ captured by an antenna at a distance D from any source and that which an isotropic antenna would capture at the same distance (in free space) is defined as the gain of the antenna [II.22] .

$$G = \eta \left(\frac{\pi D}{\lambda}\right)^2 \qquad \text{II} - 8$$

D: diameter of the parabolic antenna.

η : Antenna efficiency (efficiency) generally between 50% and 70%.

λ : Wavelength (in m, λ=c/f, c =3.108 m/s).

So in decibel:

$$G[dB] = 10 * log\eta * \left(\frac{\pi D}{\lambda}\right)^2 \qquad \text{II} - 9$$

II -3-3. Equivalent Isotropically Radiated Power (EIRP)

The EIRP (Equivalent Isotropic Radiated Power) of an antenna at a specific point is the power relative to 1W required by an isotropic transmitter placed at the same distance to produce the same flux density received from the satellite at that location. This quantity is determined by the product of the power supplied to the antenna by its gain G $_e$ in a given direction, compared to that of an isotropic antenna [II.23]

$$PIRE = P_e * G_e \qquad \text{II} - 10$$

The worst in decibel is:

$$PIRE\ [dBw] = G_e\ [dBw] + P_e\ [dBw] \qquad \text{II} - 11$$

II -3-4. Figure of merit G/TB

In the space domain, the figure of merit, also called G/TB, is an essential criterion for evaluating the performance of a station. A higher G/TB indicates better system efficiency [II.21]. In this equation, G represents the gain of the antenna and TB the noise temperature of the entire system, referred to the antenna input.

II-3-5. Channel Capacity

In the presence of noise on the transmission channel, transmission is not perfectly reliable, which requires evaluation of the probable proportion of errors on the transmitted symbols. For each transmission channel, it is possible to calculate its theoretical capacity in bits per second (b/s). This capacity represents the maximum number of bits per second that can be transmitted with as little error as desired, depending on the channel bandwidth [0, w] and the signal-to-noise ratio (S/N) at inside the canal. This relationship is known as the Shannon-Hartley theorem [II.20].

$$C = w * log_2\left(1 + \frac{S}{N}\right) \qquad \text{II} - 12$$

C: The channel capacity (bit/sec).

w : The channel size (Hz).

S/N: Signal to noise ratio

II -3-6. Noises in a satellite communications link

The main sources of noise in a satellite communication link are:

1. Noise 1: This noise is part of the signal to be transmitted and is added to the thermal noise generated by the modulator, the mixer and the power amplifier. Generally, this noise is negligible compared to the power of the useful signal and other noise sources (Figure II.11)
2. Noise 2: This is the thermal noise coming from the Earth and picked up by the satellite antenna, generally at a temperature of 300K.
3. Noise 3: This is the thermal noise generated by the satellite transponder, mainly determined by the performance of the low noise amplifier of the first amplification stage of the transponder.
4. Noise 4: This noise is received by the base station antenna in addition to the signal from the satellite. It includes sky noise (galactic background noise), atmospheric thermal noise and terrestrial thermal noise.
5. Noise 5: It comes from thermal noise generated by the base station receiver, depending on the performance of the low noise amplifier of the first amplification stage of the receiver. In addition to these noise sources, a satellite communications link may be affected by interference from other satellite communications systems [II.23].

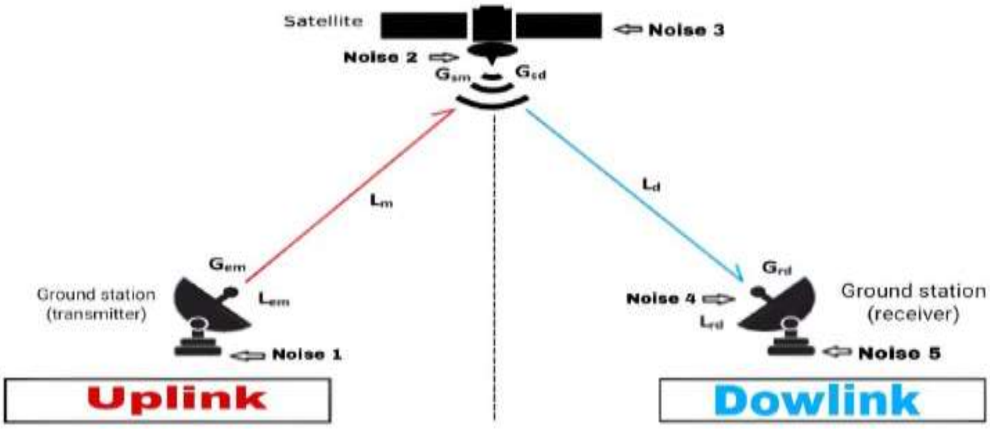


Figure II. 4: Satellite link and these parameters. [II.23].

II -3-7. Noise temperature

II -3-7-A. Noise temperature of a system

In a system, the background noise is determined by the thermal noise defined by the relation:

$$N_0 = KT_B \qquad \mathrm{II}-13$$

$$N_0[dB] = 10 * \log(K) + 10 * \log(T_B) = -228.6 + 10 * log(T_B) \qquad \mathrm{II}-14$$

K: Boltzmann constant 1.38 x 10^{-23}w /Hz/ K.

T B : Receiver temperature in degrees Kelvin.

N 0 : Power of thermal noise [II.20].

II -3-7-B. Noise temperature of a ground station antenna

$$T_A = T_S + (1 - \eta)T_0 \qquad \mathrm{II}-15$$

T A : Noise temperature due to atmospheric ions, lightning, atmospheric absorption.

T 0 : Ambient temperature in kelvin.

II -3-8. Spectral efficiency

Spectral efficiency is commonly expressed in "bits per second per hertz", symbolized by bits/s/Hz, and calculated according to the following relation [II.21]:

$$\mathrm{Eff} = \frac{D_B}{B}\left(\frac{\frac{\mathrm{bits}}{\mathrm{s}}}{\mathrm{Hz}}\right) \qquad \mathrm{II}-16$$

The usual definition is net data rate in bits per second (bps) divided by bandwidth in Hertz.

II -3-9. Link assessment for the upstream route

Consider the ratio of the carrier power to the noise at the receiver input

$$\frac{C}{N_0} = \frac{\mathrm{PIRE_{sol}G_{sat}L_m}}{K * T} \qquad \mathrm{II}-17$$

The EIRP, or Equivalent Isotropic Radiated Power, represents the product of the power supplied to the input of the transmitting antenna by its gain. In other words, EIRP is a measure of the performance of the transmitting section of a wireless communication system [II.25]

$$(PIRE)_{ground\ station} = (P_T * G_T)_{ground\ station}$$

$$= \left(\frac{P_{TX}}{L_{FTX}}\right)_{ground\ station} * \left(\frac{G_{T\ max}}{L_T}\right)_{ground\ station} \qquad \mathrm{II}-18$$

With :

$$L_T = 12 * \left(\frac{\alpha_T}{\theta_{3db}}\right)^2 (dB) \qquad \mathrm{II}-19$$

L : Losses by depointing.

$\propto$: Depointing angle of the ground station.

θ_{3dB} : Antenna opening angle .

L_{FT} : Losses between amplifier and ground station antenna.

-(1/L): Losses in free space and atmospheric losses.

(-G/T): F actor of merit of the receiver (°K − 1).

$$\left(\frac{G}{T}\right)_{SAT} = \left(\frac{G_{R\,max}}{L_R}\right)_{SAT} * \left(\frac{1}{L_{FR3}}\right)_{SAT} * \left(\frac{1}{T}\right)_{SAT} \qquad \text{II} - 20$$

(G/T): The figure of merit that describes the performance of the receiving party. With :

$$G = \frac{G_{r\,max}}{L_{FRX} * L_r} \qquad \text{II} - 21$$

L : Losses by unpointing at reception.

L_{FRX}: Losses between antenna and receiver.

T: System noise temperature (SAT).

-(1/K): Inverse of Boltzmann's constant. [II.2 5]

II -3-10. Link assessment for the downlink

Or the signal-to-noise ratio at the receiving earth station

$$\left(\frac{C}{N_0}\right)_{Down} = (PIRE)_{SAT} * \left(\frac{1}{L}\right)_{Down} * \left(\frac{G}{T}\right) * \left(\frac{1}{K}\right) \qquad \text{II} - 22$$

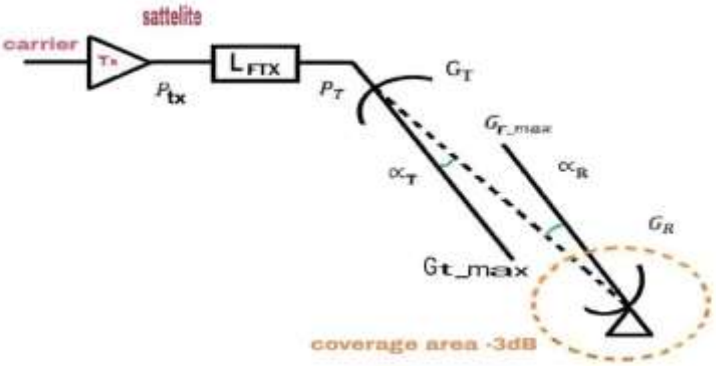


Figure II. 5: Study of the downlink [II.25].

$$(PIRE)_{SAT} = (P_T * G_T)_{SAT} = \left(\frac{P_{TX}}{L_{FTX}}\right)_{SAT} * \left(\frac{G_{R\,max}}{L_T}\right)_{SAT} \qquad \text{II} - 23$$

With :
L : Losses by de-pointing generally -3dB.
$\propto$: Depointing angle of the ground station.

$$\left(\frac{G}{T}\right)_{ground\ station}$$

$$= \left(\frac{G_{R\,max}}{L_T}\right)_{ground\ station} * \left(\frac{1}{L_{FTX}}\right)_{ground\ station} * \left(\frac{1}{T}\right)_{ground\ station} \qquad \text{II}-24$$

With :

$$L_R = 12 * \left(\frac{\alpha_R}{\theta_{3db}}\right)^2 \text{(dB)} \qquad \text{II}-25$$

∝ : Depointing angle of the ground station.

T: Ground system noise temperature.

(1 K) = Free space losses and atmospheric losses.

(1 K) = Inverse of Boltzmann's constant. [II.24]

II -3-11. Overall link assessment

The signal-to-noise ratio of the overall link is deduced from the two balances, uplink and uplink, by the following formula

$$1\Big/\left(\frac{c}{N_0}\right)^T = 1\Big/\left(\frac{c}{N_0}\right)_{up} + 1\Big/\left(\frac{c}{N_0}\right)_{Down} \qquad \text{II}-26$$

Total link noise = uplink retransmitted noise + downlink noise

Uplink :

$$\left(\frac{c}{N_0}\right)^T = \frac{C_{UP}}{N_{0\,up}} \qquad \text{II}-27$$

Downlink :

$$\left(\frac{c}{N_0}\right)_{Down} = \frac{C_{down}}{N_{0\,down}} \qquad \text{II}-28$$

Total noise :

$$\left(\frac{c}{N_0}\right) = \frac{C_{down}}{N_{0T}} \qquad \text{II}-29$$

$$\frac{C}{N_0} * \frac{1}{B_N} = \frac{C}{N} \qquad \text{II}-30$$

With

N_0: Noise equivalent spectral density (W/Hz).

$N_0 = K*T$

T: System noise temperature (°K).

$N = N_0 * B_N$

N: Total noise

B_N = Receiver bandwidth (Hz) [II.24].

II -3-12. The power received

The received power P_r can be expressed according to the Fris equation [II.20]:

$$\frac{P_r}{P_t} = G_t(\ t, \varphi_t)\, G_r(\theta_r, \varphi_r) \left(\frac{\lambda}{4\pi R}\right)^2 (1 - |\Gamma_t|^2)\, r\, |^2 e - \alpha R \qquad \text{II-31}$$

$$\mathrm{P}_r = \frac{A_r}{4\pi R^2} = P_e * G_e * R_e * \left(\frac{\lambda}{4\pi R^2}\right)^2 \qquad \mathrm{II} - 32$$

- G_t, G_r: Are linear ducts of the transmitting and receiving antennas.
- $\Gamma_t$and Γ_r: Are the reflection coefficients of the antennas.
- αtand α_r: Are the polarization vectors of the antennas.
- α: is the absorption coefficient of the medium.
- R: is the transmitter-receiver distance.

II -3-13. Calculation of link budget

In this section, we will explore the process of calculating the link budget during communication between an earth station and a low earth orbit (LEO) satellite, using the following parameters .

Settings	Values
Tx optical power [w]	0.1
Tx optical power [dBm]	20
Tx gain [dBi]	72
Rx gain [dBi]	-115.6
Pointing loss [dB]	-1.6
Atmospheric attenuation [dB]	-2.6
Rx optical loss [dB]	-3.0
Lx optical loss [dB]	-3.0
Frequency [THz]	195
Wavelength [nm]	1538
Transmitter opening diameter	25cm
Receiver opening diameter	15cm

Table II. 1: The link budget parameters [II.26].

- **Calculation results**

The table below illustrates the final link budget results of a LEO satellite (Table II.2).

Settings	Values			
Scoring strategy	Open loop			
Altitude [km]	400km	600km	800km	1000km
Elevation [º]	30.0	30.0	30.0	30.0
Transmitted divergence (e-2 radius) [µrad]	30.1	30.1	30.1	30.1
Transmitter power [dB] [w]	20 0.1	20 0.1	20 0.1	20 0.1
Transmitter gain [dB]	135.5	135.5	135.5	135.5
Free space attenuation [dB]	250.28	253.80	256.30	259.40
Free space loss [dB]	-220.28	-223.80	-226.30	-229.40
Average score-loss [dB]	-4.8	-4.8	-4.8	-4.8
Power received [dB]	-495.6	-499.2	-531.7	-571.68
WORST [dbm]	62	62	62	62
Noise temperature (k)	80	80	80	80
(G/T) figure of merit [dB/k]	0.001	0.001	0.001	0.001
EIRP (ground station) [dB]	-25.23	-25.23	-25.23	-25.23
EIRP (SAT) [dB]	26.52	26.52	26.52	26.52
(C/N) rising [dB]	299.63	231.39	230.64	216.67
(C/N) descending [dB]	169.10	167.33	166.08	165.59
(C/N) total [dB]	108.10	98.03	96.61	93.89

Table II. 2: The final link assessment results.

II -4. Conclusion

This chapter illustrates the significant impact of Big Data on communications and the need for accurate link budget calculation for satellite communications systems.

It highlights the complexity of data and the precision required in modern communications, while highlighting the challenges and opportunities offered by the era of Big Data.

Ultimately, mastery of these areas is essential for the development of information and communication technologies .

Chapter 3: Results and discussion

III.1. Introduction

Transmission of big data via terrestrial LEO laser link is constantly improving, promising reliable connectivity for future space missions. These advancements will enable rapid and efficient data transmission, thereby supporting various space applications.

In this third chapter, we look at the crucial importance of simulation in the development and improvement of Big Data transmission networks by laser link in low Earth orbit (LEO). Software simulation, particularly with Optisystem , plays an essential role in the design, analysis and optimization of these complex systems. We will explore in detail how simulation can accurately model the behavior of individual components, predict system performance under various conditions, and test different configurations before actual deployment. By examining the benefits and limitations of simulation, we will highlight its central role in advancing optical wireless communications technology and achieving efficient and reliable transmission networks to meet the growing needs for connectivity to the world. global scale. We will also analyze the different simulation results, based on the following performances: power, bit error rate (BER), quality factor (Q) and eye diagram.

III.2. Presentation of Optisystem software

OptiSystem , a software designed by the Canadian company Optiwave , specializes in the design, simulation and analysis of optical transmission systems. It offers engineers and researchers the ability to expand the range of simulated systems by integrating custom functions into the simulations. [III.1]

OptiSystem constitutes an interactive environment integrating powerful digital tools, advanced graphics functionalities and a friendly user interface. The methodology to be adopted is divided into two distinct phases:

Creating the block diagram

In-depth analysis of this diagram. [III.2]

III.2.1 Optisystem interface

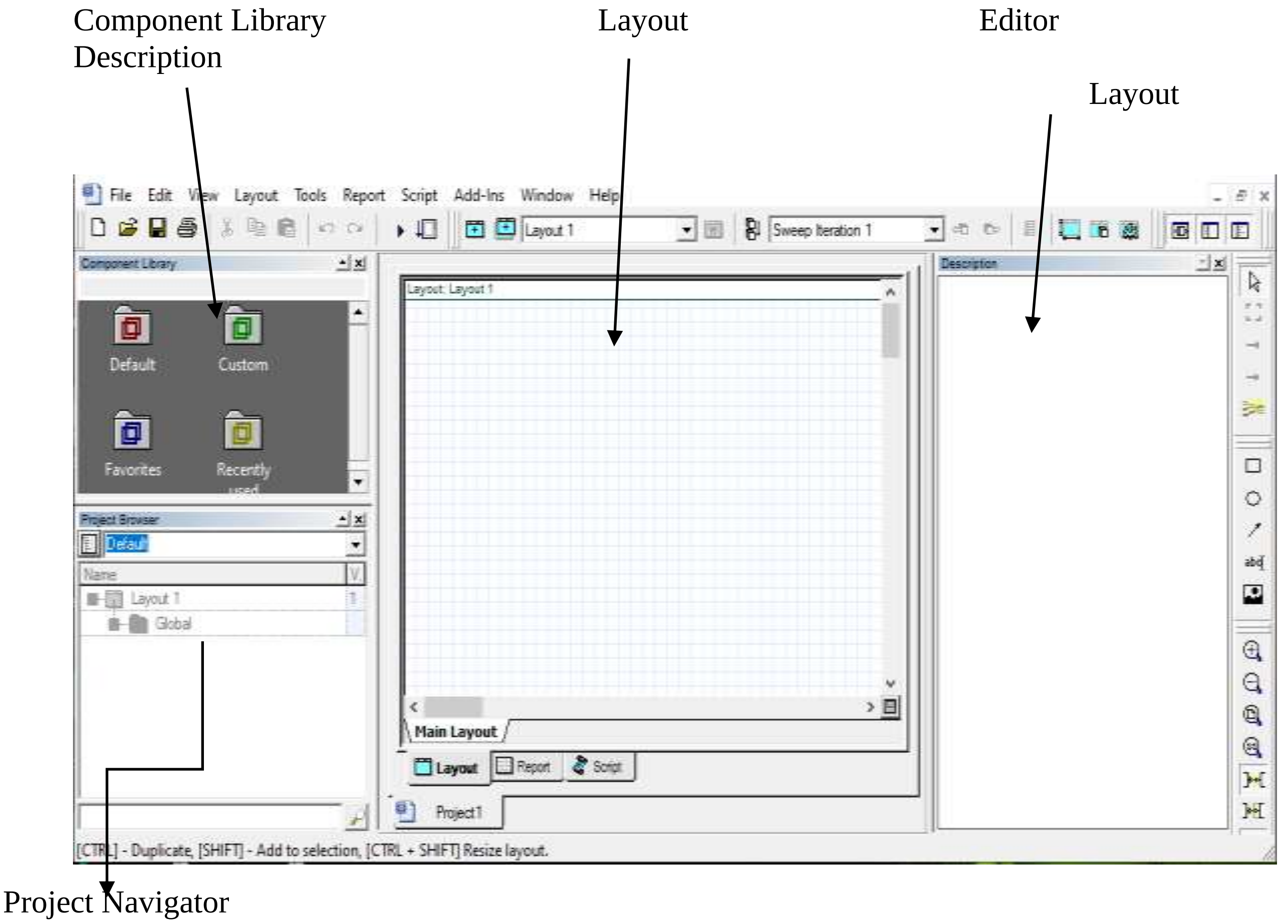
Optisystem is an Xwindows application that simplifies the design, testing and optimization of optical communications systems.

Its main window is divided into several distinct parts:

- Library: A database of various existing components.
- Layout editor : allows editing and configuration of diagrams during design.

- Current project: provides a visualization of files and components corresponding to the current project.

Its extensive library includes a variety of active and passive components with realistic parameters, making it easy to model complex optical systems. [III.3]



[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

Figure III. 1 :the Optisystem interface

III.2.2 Main characteristics of the Optisystem software

Key features of Optisystem software include:

- The ability of virtual library components to faithfully reproduce the specific behavior and effects of real components by adjusting parameters.
- The component library allows you to derive the parameters that can be measured from test and measurement equipment from different vendors.
- Visualization tools can generate representations such as sound signal, eye diagram, BER (bit error rate), etc. [III.4].

III.2.3 Optisystem software applications

Optisystem applications often used:

- Design of optical communication systems, covering components down to the physical layer level.
- Calculation of the bit error rate (BER or BER) and evaluation of the link budget.
- Design of TDM/WDM networks and passive optical networks (PON).
- Free space modeling for optical systems (OSA).
- Design of channel transmitters and optical amplifiers [III.5].

III.2.4 . Advantages of OptiSystem

- The component library makes it easy to import real-time measurements from devices supplied by various test and measurement vendors.
- Summarizes the overall performance of the OWC system.
- Provides direct access to all system depth element data.
- Intuitively presents conceptual strategy to potential customers [III.6].

III.2.5 Simulation modes

Optisystem offers three distinct simulation modes:

- Normal mode: it simply involves entering the desired value for the parameter.
- Sweep mode : here, the parameter value varies following a predefined curve.
- Scripted mode: in this case, the parameter is evaluated as an arithmetic expression. [III.7]

III.2.6 Signal Representation in Optisystem

- To improve the flexibility and efficiency of the simulation tool, it is crucial that it offers a range of models at different levels of abstraction, covering systems, subsystems and individual components. [III.8]
- Optisystem offers a hierarchical structuring of components and systems, which allows the use of specialized tools for integrated optics. This approach allows the simulation to reach the required level of precision. Different levels of abstraction require varying signal representations. The representation of signals should be as detailed as possible to ensure effective simulation. [III.8]

In the software library, there are five types of signals, each identified by a specific color code, as shown in the table below:

Binary	Red
M-Ary	Dark red
Electric	Blue
Optical	Green
Every type	Dark green

Table III. 1: Color of the connection signal [III.9].

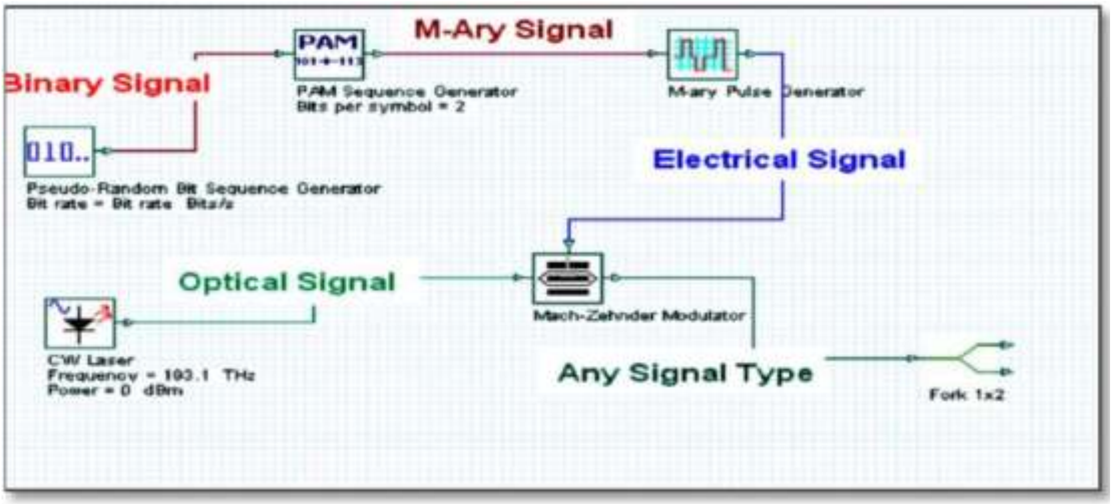


Figure III. 2: R epresentation of signals under Optisystem[III.9]

III.2.6.A Electrical signals

Electrical signals are generated by elements such as pulse generators for transmitters and photodetectors for receivers. They materialize in the form of sampled temporal waves. The fundamental characteristics of these signals lie in their temporal noise levels and their frequency noise power spectra.

III.2.6.B Binary signals

Binary signals are produced by devices such as bit sequence generators. They are used as input by pulse generators in the transmitter library and digital switches in the network library. A binary signal is a succession of "1s" and "0s", also described as alternating between marks and spaces. The key characteristic of a binary signal is its bit rate.

III.2.6.C Optical signals

Optical signals are created by things like lasers in the transmitter library. They offer various signal representations, including:

- Sampled signals
- Parameterized signals
- Noisy signals

III.2.6.D M-Ary signals

M-Ary signals are multi-level signals used in special coding techniques such as PAM, QAM, PSK and DPSK. They have similarities with binary signals, but unlike the latter which only have two levels (high and low, or 1 and 0), M-Ary signals can adopt various levels. In other words, they are not limited to brand and space values alone [III.8].

III.2.7 Criteria and methods for evaluating transmission quality

There are several standards for evaluating the quality of optical transmission. Among these, the three main criteria are signal eye diagram, bit error rate (BER), and Q factor.

III.2.7.A Eye diagram

The eye diagram offers a "visual" representation of the quality of the signal by superimposing all the binary symbols of the signal.

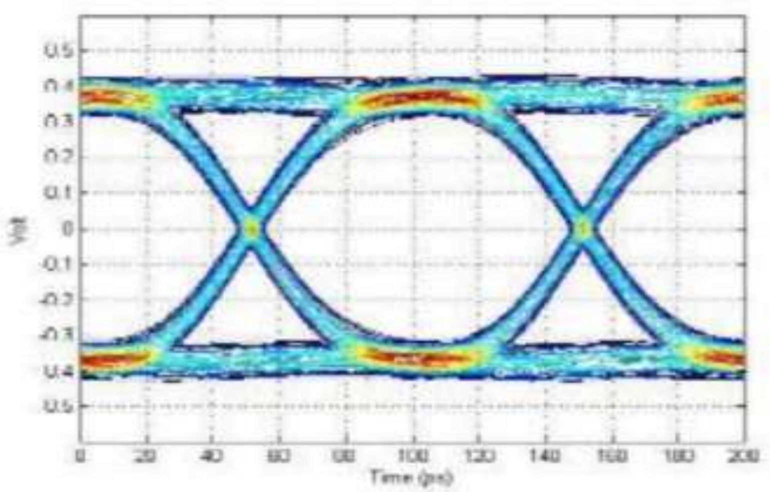


Figure III. 3: Eye diagram of a signal in NRZ format.

A wider aperture of the pattern is associated with better signal quality, while a higher quality factor indicates increased ease of detecting error-free signals. Therefore, the eye diagram provides an effective visual method to assess the signal quality in the response range of the photodiode, using the oscilloscope [III.10].

Figure II.14 shows the eye diagram of the NRZ signal

III.2.7.B Bit error rate (BER)

To evaluate the quality of binary digital transmission, it is necessary to compare the sequence of symbols transmitted with that of symbols received in order to calculate the number of error bits. This number corresponds to the number of errors detected, i.e. the number of times a “0” symbol is received instead of a “1” symbol, and vice versa. Then, this value is normalized by dividing the number of bits in error by the total number of bits transmitted.

$$BER = \frac{Number\ of\ error\ bits}{Number\ of\ transmitted\ bits} \qquad \text{III. 1}$$

For a high-quality optical communication system, the bit error rate (BER) is generally kept below 10^{-9} or 10^{-12}, depending on the system specifications [III.10].

III.2.7.C Quality factor Q

The quality factor is defined as the signal-to-electrical noise ratio at the input of the receiver decision circuit. The measured signal includes both the component due to the useful signal as well as the noise contribution coming from all elements of the transmission chain. The Q factor is then defined as follows:

$$Q = \frac{\mu_1 - \mu_0}{\sigma_1 1 - \sigma_0} \qquad \text{III. 2}$$

Considering µ1 et µ0as the average levels of the useful signal (representing the symbols "1" and "0" respectively), $\sigma 1 et \sigma 0$as the deviations of the optical powers around these average levels (representing the noise) in the eye diagram which illustrates the signal measured, in the case where the power distribution of the symbols is Gaussian, the quality factor is linked to the BER (bit error rate) by the following relationship [III.11].

$$TEB = \frac{1}{2}\left[erfc\ \frac{Q}{\sqrt{2}}\right] \qquad \text{III. 3}$$

III.3 Simulation of a transmission chain by OWC

IsOWC system uses a laser beam to establish wireless connectivity between the transmitter and receiver, exploiting free space as a medium for transporting information. The properties of the propagation medium have a significant impact on the performance of the system [III.12].

At the transmitter we used a CW laser at 195 THz with a power of 25 dBm. Data is generated by a pseudo-random bit sequence generator at a rate of 5 bits/s, then modulated via a Mach-Zehnder modulator and sent via an OWC channel over distances of 400km, 600km, 800km, 1000km.

In the receiver, a photodetector (APD) detects the signal, followed by a Bessel low-pass filter whose cutoff frequency is 0.75 times the bit rate. A BER analyzer then evaluates the system performance, calculating the Q factor and generating the eye diagram for analysis.

Laser power monitoring is carried out using an optical power meter (Optical Power Meter_1) and an optical spectrum analyzer (Optical Spectrum Analyzer_1). The propagation channel has additional losses of 1.49 dB, with telescope apertures of 25 cm for the transmitter and 15 cm for the receiver (figure III. 4)

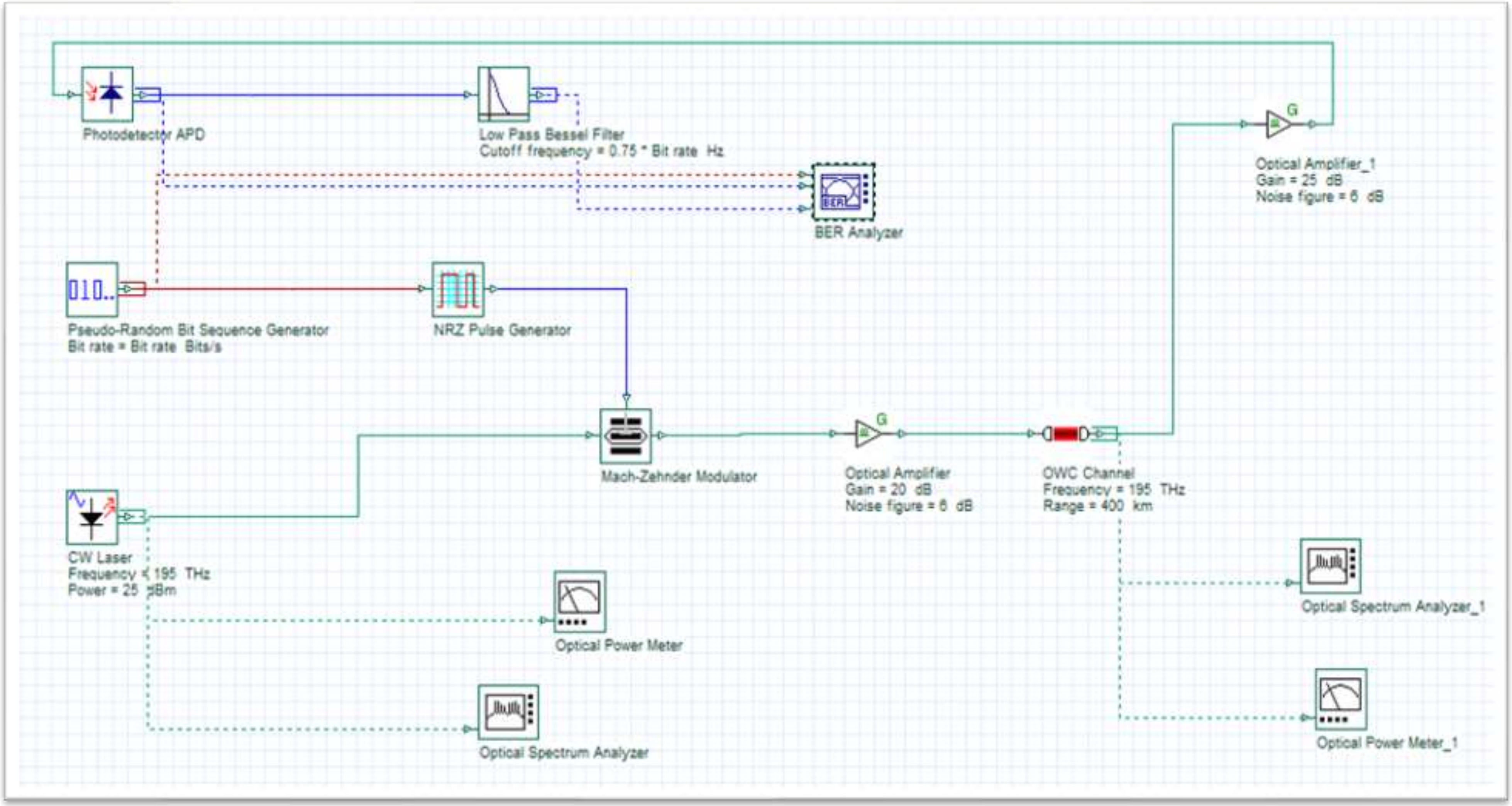


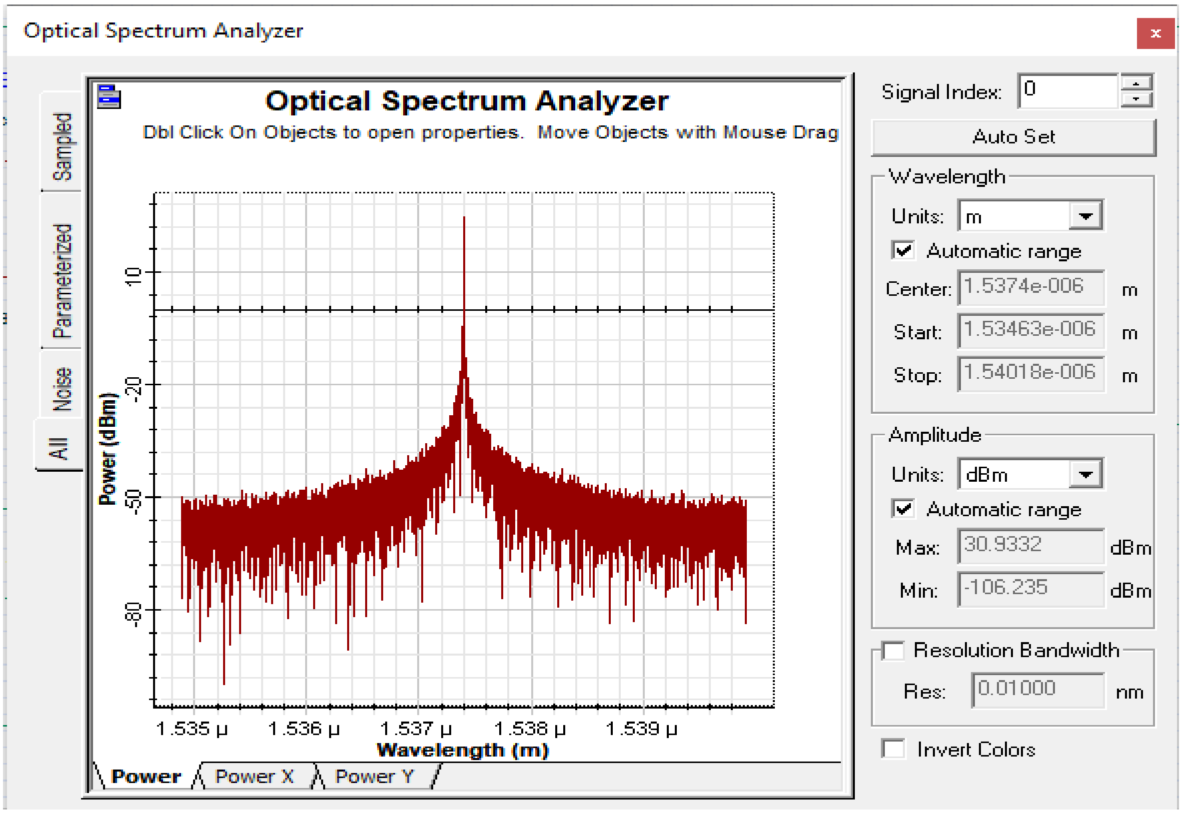
Figure III. 4:Schematic of the proposed structure for LEO satellite intercommunication.

Settings	Values
Laser	C.W.
Wave length	1538nm
Transmitting power	25dBm
Distance	400km, 600km, 800km, 1000km.
Data rate	1e+010 bit/s
Modulation	NRZ
Detector photo	ODA
Pointing errors	1 urad
Additional losses	1.49 Db
Transmitter opening diameter	25cm
Receiver opening diameter	15cm
Mitigation	0.09 dB/km

Table III. 2: The simulation parameters

III.4 Results and discussion

This figure represents the transmitted optical power spectrum of the optimized link which is estimated at $316.228 * 10^{-3}$ watt, calculated by the wattmeter. This power transmitted at the wavelength 1538nm for distances of 400km, 600km, 800km, 1000km.



Signal Index: 0

Wavelength

Units: m

☑ Automatic range

Center: 1.5374e-006 m

Start: 1.53463e-006 m

Stop: 1.54018e-006 m

Amplitude

Units: dBm

☑ Automatic range

Max: 30.9332 dBm

Min: -106.235 dBm

☐ Resolution Bandwidth

Res: 0.01000 nm

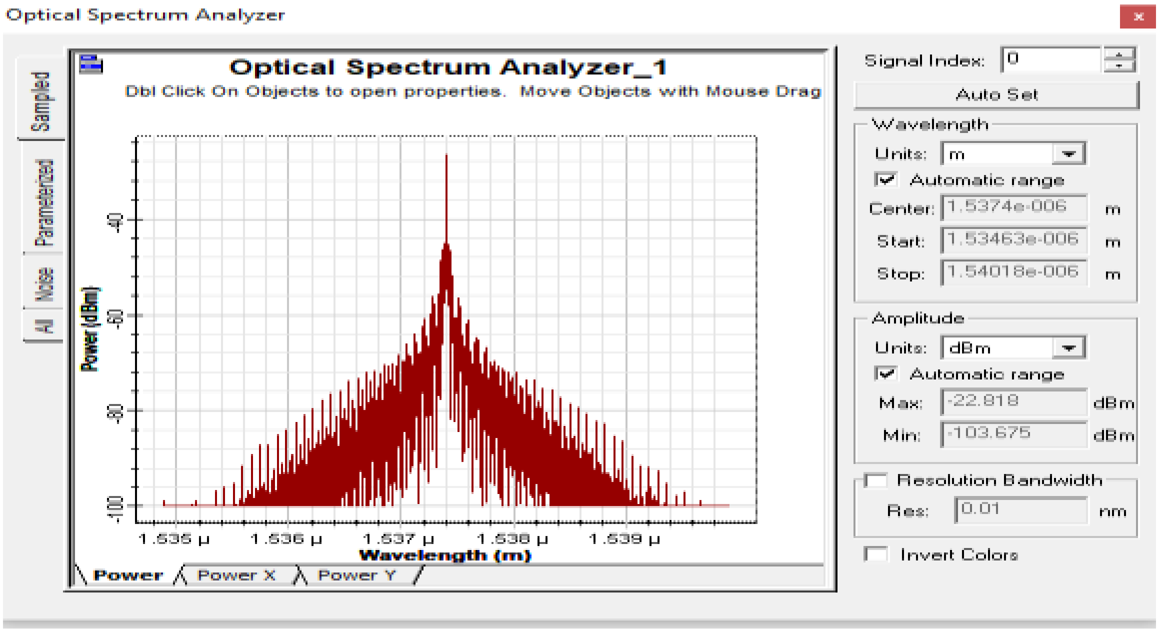
☐ Invert Colors

Figure III. 5:Optical power transmitted at a wavelength of 1538nm.

III.4.1 Leo satellite transmission For a distance of 400 km

The following figure shows the power spectrum received for a distance of 400km and gain of 20dbm.

The maximum received power value is -22.818 dbm and the minimum power equals -103.675dbm



Signal Index: 0

Wavelength

Units: m

☑ Automatic range

Center: 1.5374e-006 m

Start: 1.53463e-006 m

Stop: 1.54018e-006 m

Amplitude

Units: dBm

☑ Automatic range

Max: -22.818 dBm

Min: -103.675 dBm

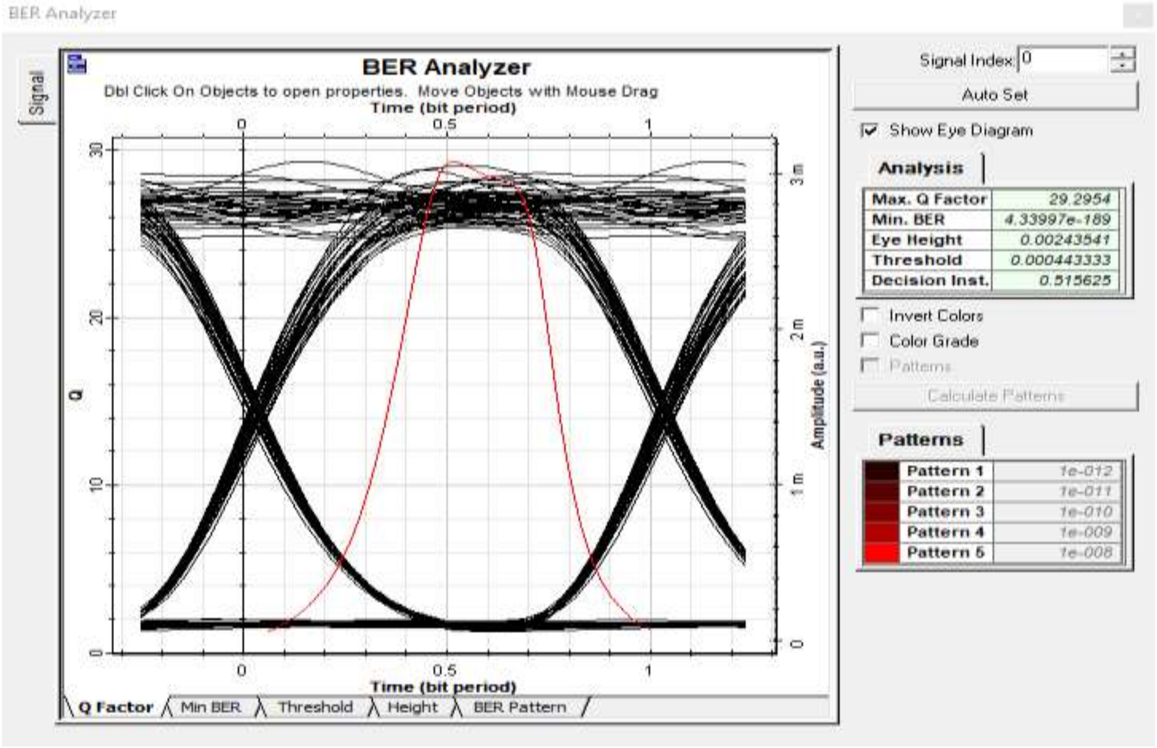
☐ Resolution Bandwidth

Res: 0.01 nm

☐ Invert Colors

Figure III. 6:Optical power received for a link distance of 400 km.

To check the transmission quality you must see the eye diagram and the Q factor quality which is shown below :



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	29.2954
Min. BER	4.33997e-189
Eye Height	0.00243541
Threshold	0.000443333
Decision Inst.	0.515625

☐ Invert Colors

☐ Color Grade

☐ Patterns

Patterns

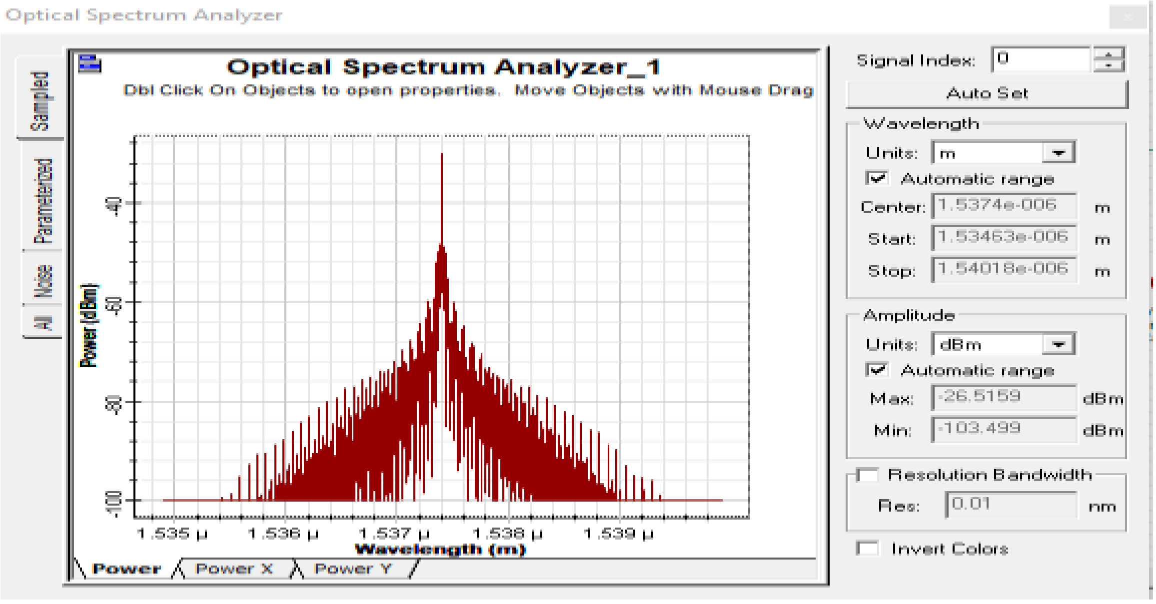
🟥	Pattern 1	1e-012
🟥	Pattern 2	1e-011
🟥	Pattern 3	1e-010
🟥	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure III. 7:Q factor quality with an eye diagram in a distance of 400 km and a transmitter gain of 20 dBm.

- The Max Q factor estimates at 29.2954 and the Min BER is 4.33 e-189.

III.4.2 Leo satellite transmission For a distance of 600 km

For a gain of 38 dBm and a distance of 600 km:



Signal Index: 0

Wavelength

Units: m

☑ Automatic range

Center: 1.5374e-006 m

Start: 1.53463e-006 m

Stop: 1.54018e-006 m

Amplitude

Units: dBm

☑ Automatic range

Max: -26.5159 dBm

Min: -103.499 dBm

☐ Resolution Bandwidth

Res: 0.01 nm

☐ Invert Colors

Figure III.8:Optical power received for a link distance of 600 km and a transmitter gain of 38 dBm.

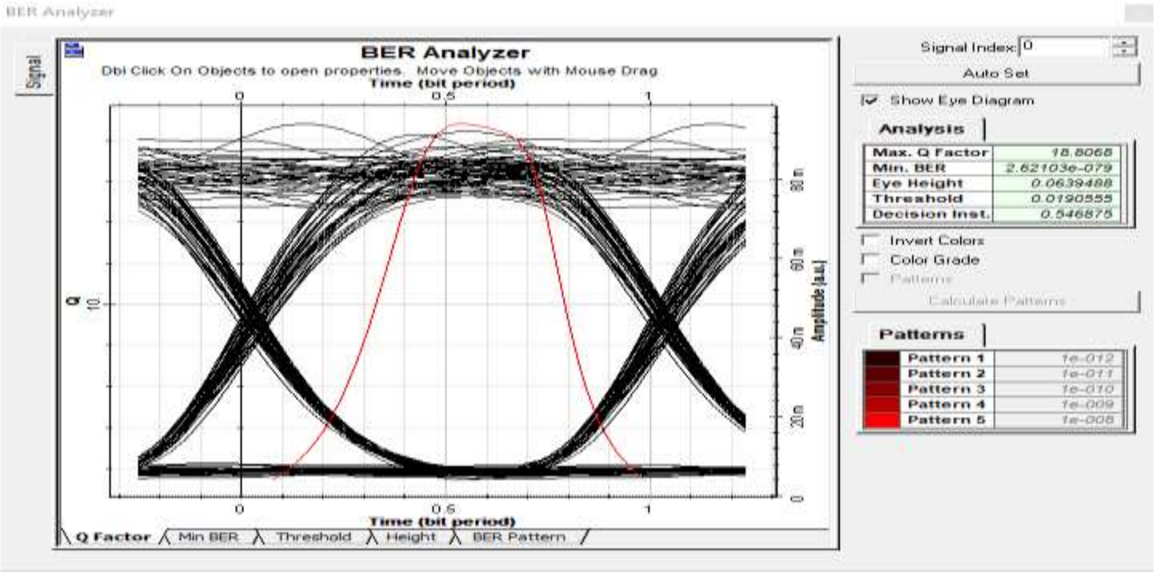
The Max value: -26,5159

Min value: -103,499

- The eye diagram and the Q factor after increasing the transmitter gain value:

The Max Q factor: 18.8068

The Min BER: 2.62 e-079



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	18.8068
Min. BER	2.62103e-079
Eye Height	0.0639488
Threshold	0.0190555
Decision Inst.	0.546875

☐ Invert Colors

☐ Color Grade

☐ Patterns

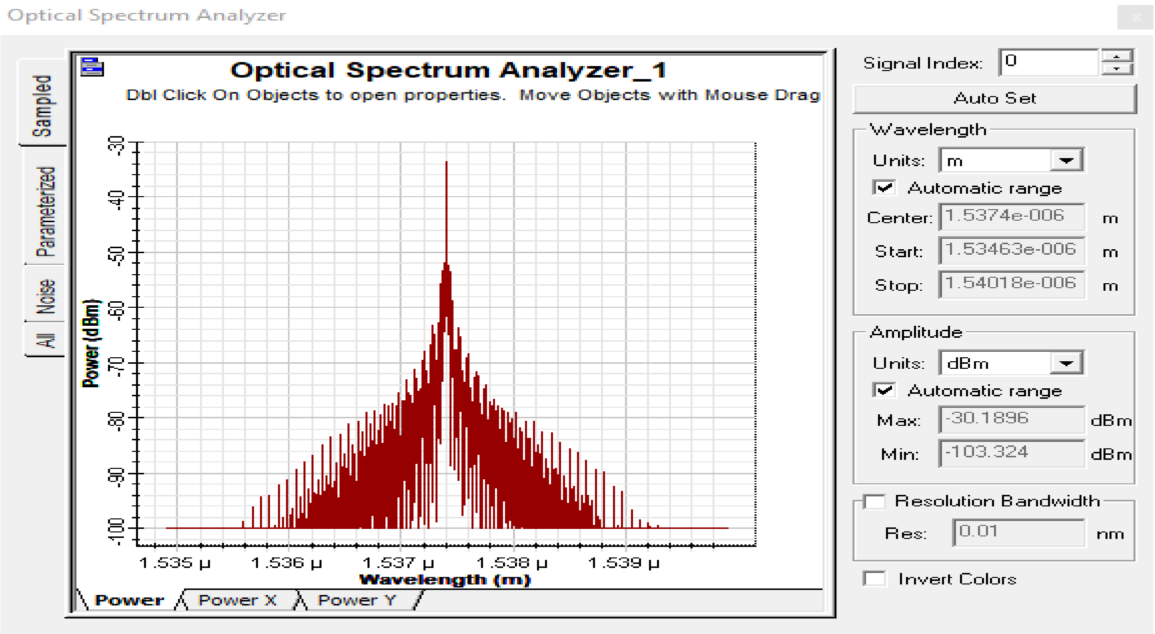
Patterns

🟥	Pattern 1	1e-012
🟥	Pattern 2	1e-011
🟥	Pattern 3	1e-010
🟥	Pattern 4	1e-009
🟥	Pattern 5	1e-008

Figure III.9:Quality Q factor with an eye diagram in a distance of 600 km and a gain of 38 dBm

III.4.3 Leo satellite transmission for a distance of 800 km

The optical power spectrum received for a distance of 800 km and a gain of 60 dBm



Signal Index: 0

Wavelength
Units: m
☑ Automatic range
Center: 1.5374e-006 m
Start: 1.53463e-006 m
Stop: 1.54018e-006 m

Amplitude
Units: dBm
☑ Automatic range
Max: -30.1896 dBm
Min: -103.324 dBm

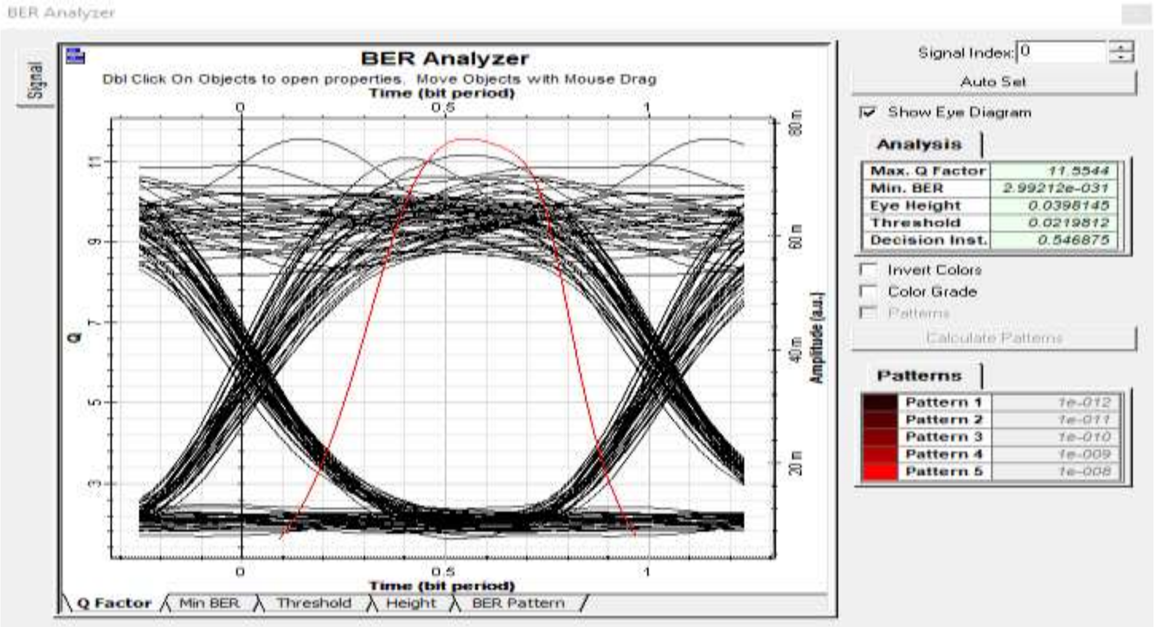
☐ Resolution Bandwidth
Res: 0.01 nm

☐ Invert Colors

Figure III. 10:Optical power received for a link distance of 800 km and a transmitter gain of 40 dBm.

The max received power is -30.18 and the min power is -103.324

- The eye diagram and the quality factor Q for a distance of 800 km and a gain of 40 dBm:



Signal Index: 0

☑ Show Eye Diagram

Analysis

Max. Q Factor	11.5544
Min. BER	2.99212e-031
Eye Height	0.0398145
Threshold	0.0219812
Decision Inst.	0.546875

☐ Invert Colors
☐ Color Grade
☐ Patterns

Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

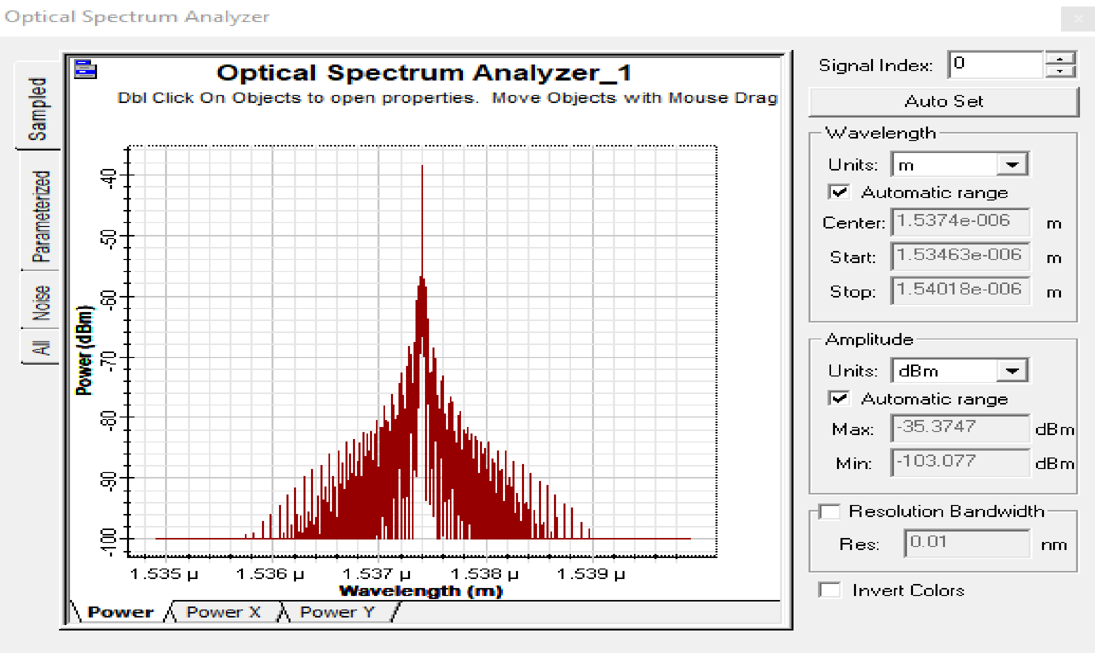
Figure III. 11:Q factor quality with an eye diagram in a distance of 800 km and a gain of 40 dBm.

Max Q factor: 11.5544

Min BER: 2.99 e-031

III.4.4 Leo satellite transmission For a distance of 1000km

The optical power spectrum received for a distance of 1000km and a gain of 45 dBm



Signal Index: 0

Units: m

☑ Automatic range

Center: 1.5374e-006 m

Start: 1.53463e-006 m

Stop: 1.54018e-006 m

Units: dBm

☑ Automatic range

Max: -35.3747 dBm

Min: -103.077 dBm

☐ Resolution Bandwidth

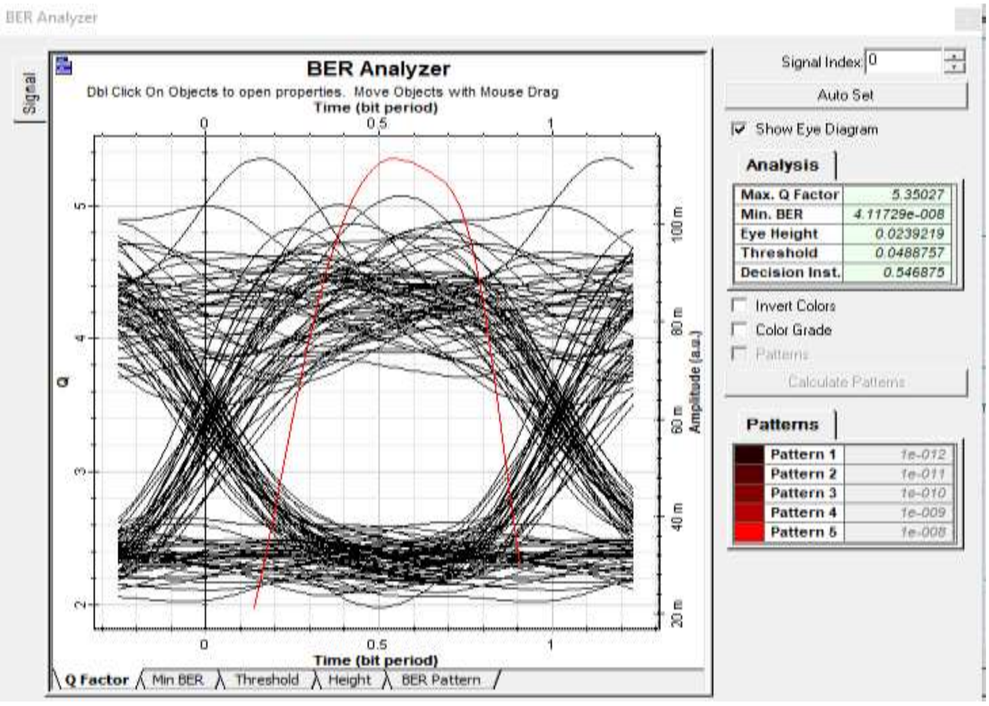
Res: 0.01 nm

☐ Invert Colors

Figure III. 12:Optical power received for a link distance of 1000 km and gain of 45 dBm.

The Max received power value: -35.37 dBm and the Min value: -103.077 dBm

The following figure represents the eye diagram and the Q factor:



Signal Index: 0

☑ Show Eye Diagram

Max. Q Factor	5.35027
Min. BER	4.11729e-008
Eye Height	0.0239219
Threshold	0.0488757
Decision Inst.	0.546875

☐ Invert Colors

☐ Color Grade

☐ Patterns

Pattern 1	1e-012
Pattern 2	1e-011
Pattern 3	1e-010
Pattern 4	1e-009
Pattern 5	1e-008

Figure III. 13:Q factor quality with an eye diagram in a distance of 1000 km and a gain of 45 dBm.

The value of Q factor: 5.350, and the value of Min BER: 4.11 e-008

Summarize the simulation results in the following table:

Distance [km]	Gain [dB]	Puissance emis	MinBER	Q facture	Power received [dBm]	
					Max	Min
400	20	25	4.33 e-189	29.29	-22,818	-103,818
600	38	25	2.62 e-079	18.80	-26.5159	-103,499
800	40	40	2.99 e-031	11.55	-30.1896	-103,1896
1000	45	50	4.11 e-008	5.35	-35.37	-103,077

Table III. 3:Analysis results

III.4.6 Oblique distance

The slant range calculator determines the distance (R) between a ground station and an object (such as a satellite or aircraft) using the respective altitudes of the station and object, as well as the angle of elevation (α) [III.13].

$$R = f(oA, sA, \alpha) \qquad III.4$$

- **(sA)** Altitude of the station above the mean Earth radius;
- **(α)** Elevation angle between the station above the horizon and the object;
- **(oA)** Altitude of the object relative to the average Earth radius.

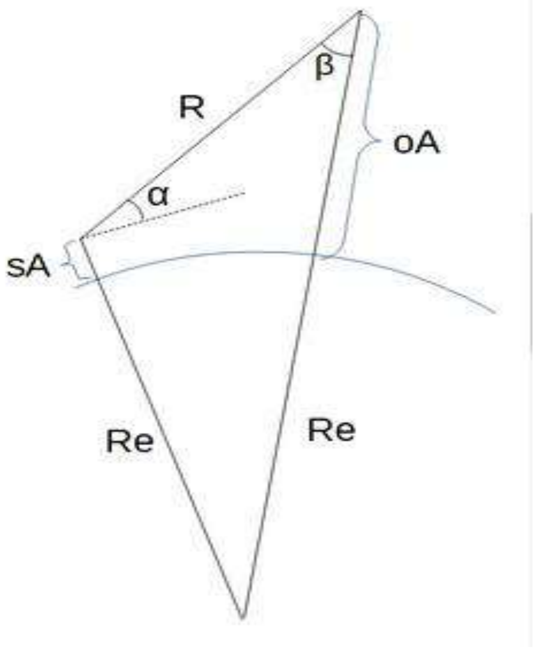


Figure III. 14: Diagram 01 of intercommunication system for oblique distance [III 13].

Oblique Span (R): In the triangle which has an obtuse angle, the span distance can be calculated using both the law of sines and the law of cosines.

- $b = Re + sA \qquad III - 5$
- $a = Re + oA \qquad III - 6$
- this is the tilt range
- CA is the central angle of the Earth
- BA is the subtended angle (β)
- AA is the elevation angle (α) + 90°.

Law of sines:

$$\frac{\alpha}{\boldsymbol{sin}(AA)} = \frac{b}{\boldsymbol{sin}(BA)} = \frac{c}{\boldsymbol{sin}(CA)} III.7$$

Law of cosines:

$$c = \sqrt{\alpha^2 + b^2 - 2\alpha.b.cos\,(CA)} \qquad III.8$$

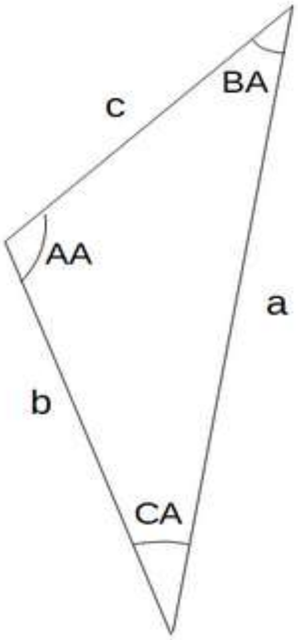


Figure III.15: Diagram 02 of intercommunication system for oblique distance [III-13].

To evaluate several parameters such as BER (bit error rate), Q-factor, power, etc., we have selected two specific points. Ain Temouchent University , located at an altitude of 670 km with the satellite, as shown in Figure III.22 below. We applied the slant distance law using OptiSystem software to perform the necessary calculations.

Figure III.16: Ain Témouchent University

III.4.5 Variation of parameters

III.4.5.A Effect of elevation

Initial phase [°]	0	10	20	30	40	50	60	70	80	90
Distance [km]	2997	2088	1526	1188	980	847	761	708	679	670
Q factor	12.88	14.82	17.72	19.19	20.20	23.74	25.87	27.23	27.13	30.52
BER	2.23 e-038	3.85 e-050	1.00 e-070	1.64 e-082	3.18 e-091	4.72e-126	4.53 e-148	1.01 e-163	1.37e-162	4.28 e-205
$P_é$ [dBm]	190	115	73	67	57	50	42	37	35	35
P_r [dBm]	-29.35	-28.35	-26.98	-26.36	-25.95	-24.65	-23.94	-23.53	-23.55	-22.58
Gain [dB]	100	91	81	55	45	40	40	40	39	39

Table III. 4: Effect of elevation

This data illustrates variations in initial phase, distance traveled, Q factor, bit error rate (BER), transmitted power, received power and gain over a range of various values **.** We can observe a progressive decrease in the transmitted power and the gain.and an increase in the Q factor, The BER values are extremely low, This indicates very good transmission quality, with a minimal risk of errors despite the distances traveled

This figure represents graphical columns of initial phase variation (elevation): When the elevation increases the distance and the power transmitted and the gain thus the BER decreases The Q factor and the power received increase with the increase in the initial phase, There appears to be a trade-off between transmission distance and signal quality. As the initial phase increases, the range decreases, but the quality and reliability of the transmission increases significantly.

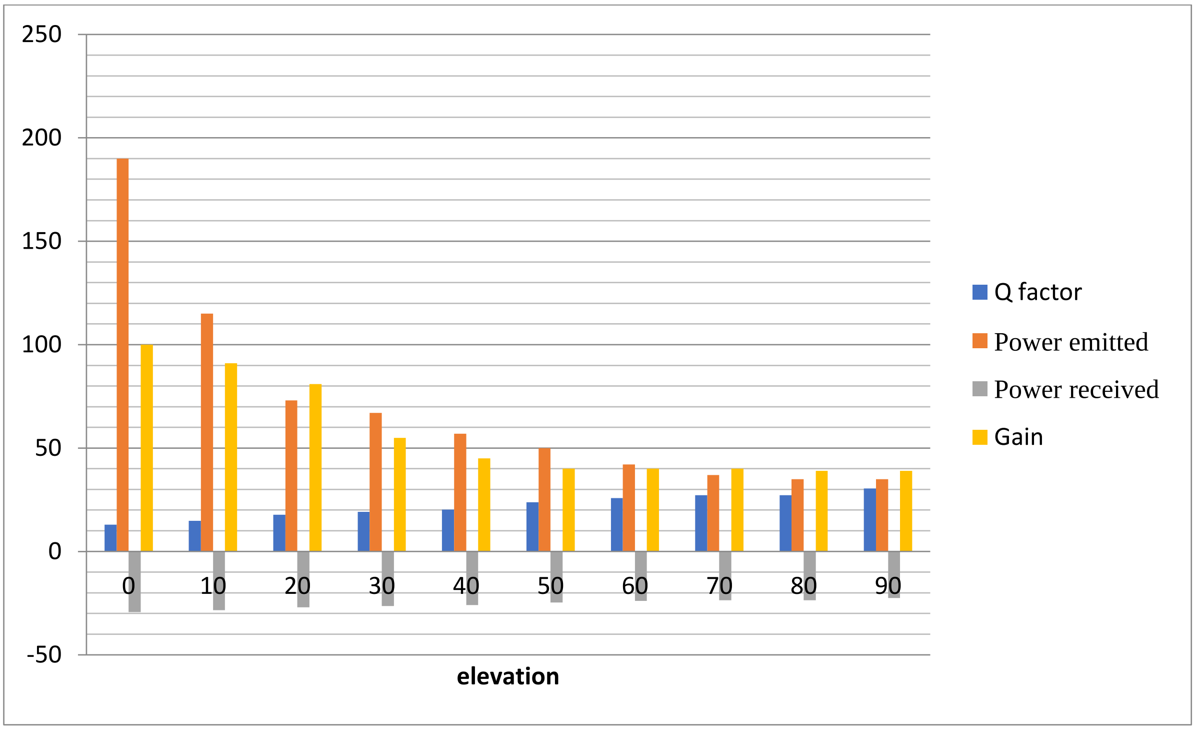


Figure III.17: Initial phase variation (elevation) [°].

III.4.7.B Effect of telescope aperture

Opening	20	30	40	50	60
Q factor	11.07	16.05	18.95	19.74	18.69
BER	6.80e-029	2.07e-058	1.49 e-080	3.67 e-087	2.17e-078
Pe [dBm]	25				
Pr [dBm]	-30.49	-27.74	-26.45	-26.13	-26.56
Gain [dB]	42	40	38	37	36

Table III. 5: Effect of telescope aperture.

Observation :

. Table III.5 shows the impact of the aperture size of a telescope on various key parameters of an optical communications system. Six different openings are compared, ranging from 20 cm to 60 cm.

For each aperture, the table displays the quality factor (Q factor), bit error rate (BER), transmitted power in decibel-milliwatts (dBm), received power (dBm), and system gain in decibels (dB).

It is observed that the Q factor and BER fluctuate irregularly with increasing aperture. On the other hand, the transmitted power remains relatively stable, while the received power gradually decreases. The system gain follows a similar trend to the received power, decreasing as the aperture size increases.

-there is an inverse relationship between telescope aperture and gain

The emitted and constant power value is 25 dbm

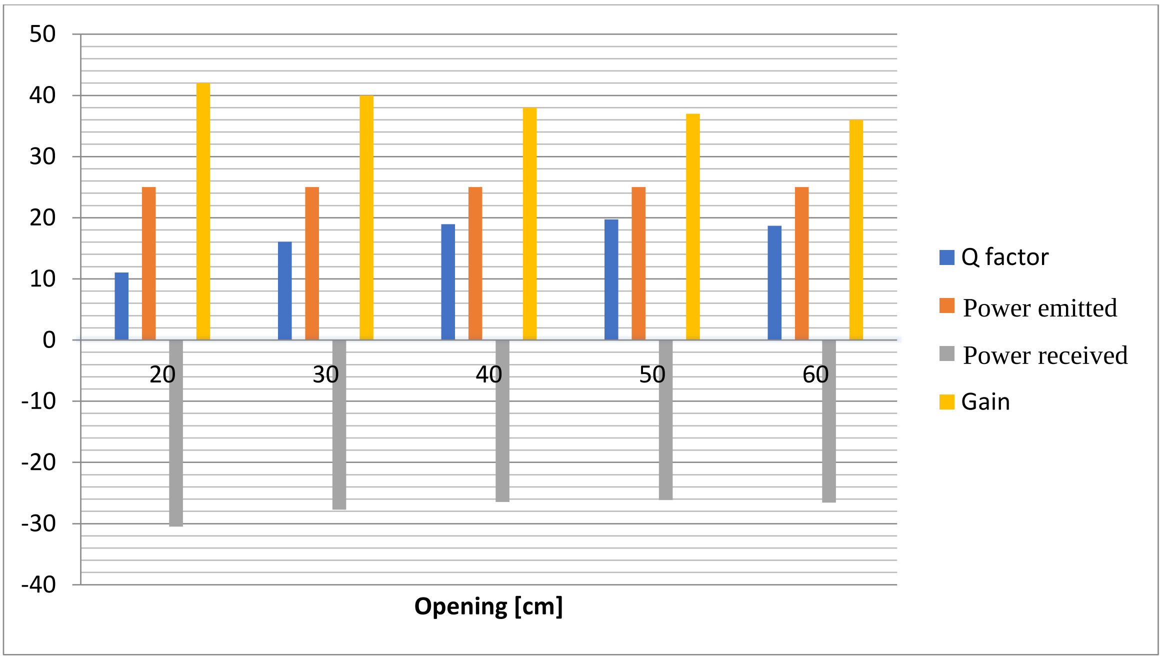


Figure III.18: Telescope aperture variation [cm].

The data shows that telescope aperture has a significant impact on signal quality, received power, and bit error rate. A larger aperture generally improves signal quality and received power up to an optimal aperture of approximately 50 cm. Beyond this opening, additional improvements are marginal and may even deteriorate slightly. These observations suggest that there is an optimal point for telescope design, balancing signal quality and received power to minimize transmission errors.

Optimizing the telescope aperture is crucial to maximizing the performance of an optical communications system. The optimal values observed in this table (50 cm opening) provide valuable information for the design of such systems.

III.4. 5.C Frequency variation

Frequency [THz]	145	165	185	195	215
Wavelength [nm]	2067	1816	1620	1537	1394
Q factor	6.39	9.86	14.94	16.32	22,026
BER	8.008e-011	2.83 e-023	8.59 e-051	2.45 e-060	7.87e-108
P $_{é}$ [dBm]	25				
P $_{r}$ [dBm]	-48.61	-47.56	-46.51	-27.61	-45.46
Gain [dB]	22	23	24	42	25

Table III. 6: Frequency variation

Observation :

This table presents different measurements and characteristics depending on the frequency for values from 145 THz to 215 THz :

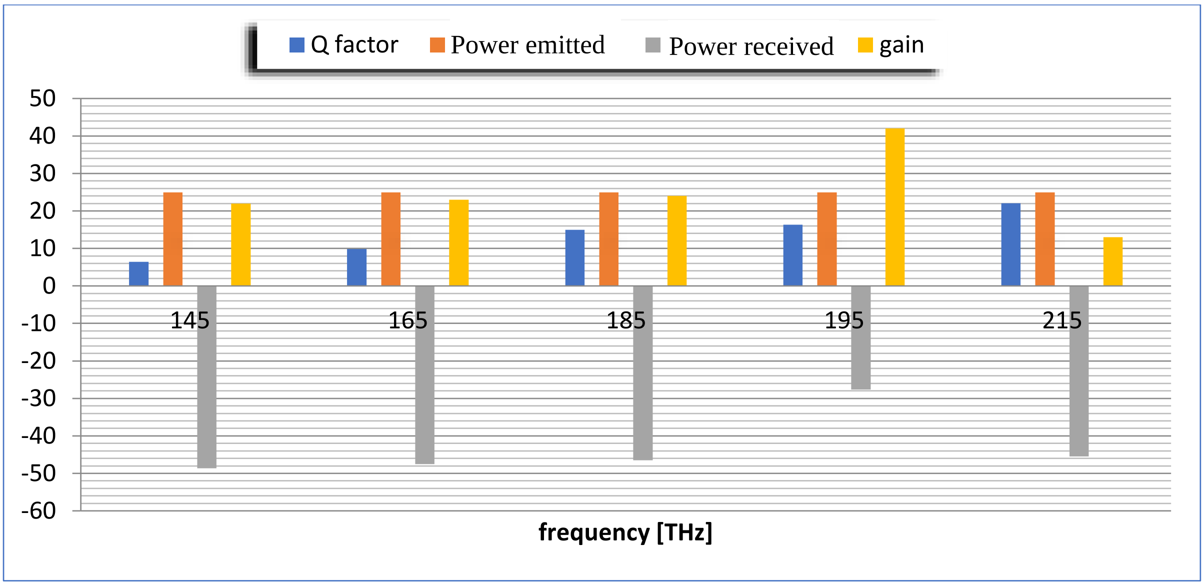


Figure III.19: Frequency variation [THz].

Several interesting trends can be observed:

The wavelength decreases as the frequency increases, which is consistent with the fundamental relationship between frequency and wavelength for light The Q factor increases with frequency, The BER decreases exponentially with increasing frequency Stable transmitted power Received power Received power increases with increasing frequency. It goes from -48.61 dBm to -45.46 Gain varies slightly with frequency, gradually increasing from 22 dB at 145 THz to 25 dB at 215 THz, except for a notable increase to 42 dB at 195

THz. This increase corresponds to the increase in received power, suggesting an improvement in system performance at this frequency.

Data shows that increasing the transmission frequency generally improves the signal quality (Q factor) and reduces the bit error rate (BER). Received power and gain also show improvements at higher frequencies, with particularly notable performance at 195 THz . This suggests that higher frequencies can provide significant benefits for optical communications systems, although specific conditions can sometimes create anomalies in the observed trends .

III.4.5. D Variation BIG DATA

Big Data	10	50	100	300	500	700	1000
Q factor	24.30	9.38	5.61	6.47	10.92	8.63	8.18
BER	6.38e-131	2.94e-021	2.84e-008	4.21e-011	3.54e-028	2.41e-018	1.05e-016
Transmitted power [DBm]	25	25	25	25	25	25	25
Power received [DBm]	-24.41	-24.20	-24.17	-18.90	-13.65	-13.65	-13.65
Gain [DB]	40	40	40	45	50	50	50

Table III. 7: Variation of BIG DATA.

This table shows the performance of a transmission of different data (Big Data) (ranging from 10Gbps to 1000Gbps) in terms of quality (Q factor), reliability (BER), and signal power variations (received power) with a amplification (gain) and constant transmitted power. With increasing data volume, the Q factor decreases, indicating a degradation in signal quality. The bit error rate (BER) increases, signaling a decrease in accuracy. However, the received power and gain increase, which partially compensates for these degradations and shows the importance of amplification to maintain system performance.

This figure shows the variation of Big Data in the form of graphical columns noting that the increase in the volume of data is accompanied by a decrease in factor Q and an increase in BER and the gain and power received which underlines the importance gain to maintain system performance.

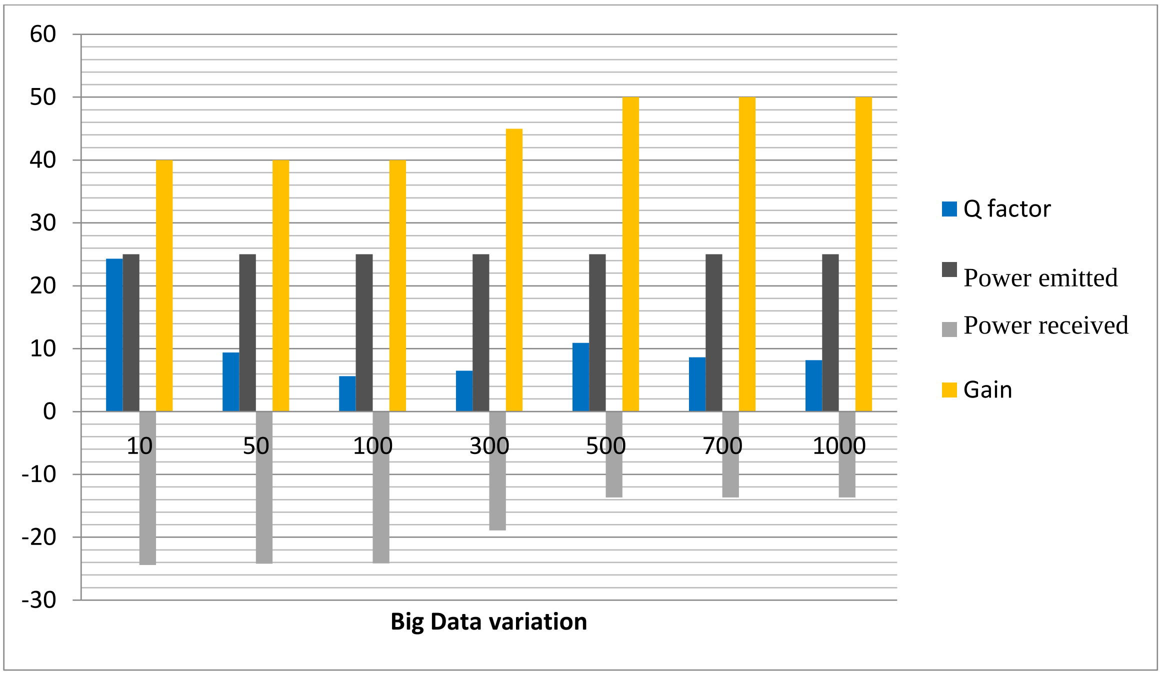


Figure III.20: Variation of Big Data

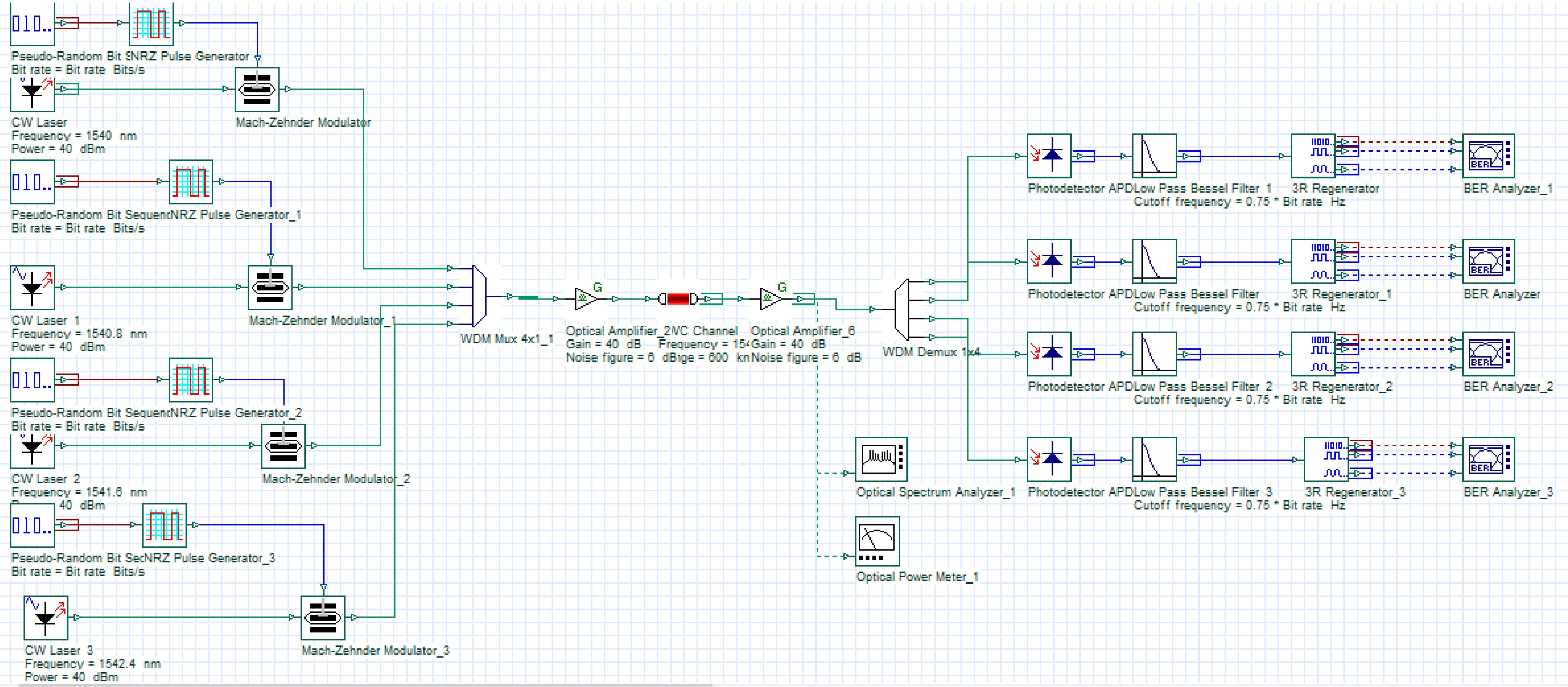


Figure III. 21: BIG DATA simulation with WDM.

This figure represents the simulation of BIG DATA transmission via Leo laser link. In this simulation, the 4x1 WDM multiplexer was used in the transmission part to combine four optical signals at different wavelengths into a single signal with a channel spacing of 0.8 (ultra dense WDM) and with a transmitted power of 40 dBm. And in the receiving part we used a 4x1 WDM demultiplexer which divides the input optical signal into four distinct channels depending on the wavelengths.

The following table shows the different laser waveforms that we used in the simulation

Laser frequency 1	1540nm
Laser frequency 2	1540.8nm
Laser frequency 3	1541.6nm
Laser frequency 4	1542.4nm

Table III. 8: Frequency space

III.4.5. E Big Data with WDM

Big Data [Gbit]	1	2.5	5	7.5	10	12.5	15
Q factor	28.57	21.12	12.16	9.59	4.41	3.03	3.37
BER	5.42 e-180	1.64e-99	1.82e-34	2.74 e-22	3.83 e-6	1.09 e-5	1.02 e-3
$P_{\acute{e}}$ [dBm]	40						
P_r [dBm]	-6.07	-6.0	-6.11	16.24	0.013	55	65
Gain [dB]	15	15	15	30	40	50	55
	15	15	15	30	40	50	55

Table III. 9: BIG DATA variation with WDM

The following table presents the different data capacities (Big data) with WDM ranging from 1 Gbps to 15Gbps in terms of variation of Q factor and BER and power received with transmitted power and gain. We note that:

The Q factor decreases, indicating a decrease in selectivity and signal quality.

The bit error rate (BER) increases, which means an increase in errors.

The gain and received power increase, indicating better system efficiency in receiving signals.

In summary, with the increase in data volume, the system shows an improvement in reception efficiency (increase in gain and received power), but this comes at the expense of signal quality (decrease in signal factor Q) and precision (increase in bit error rate). These observations suggest that the system can handle larger data volumes, but with increasing challenges in terms of signal quality and accuracy.

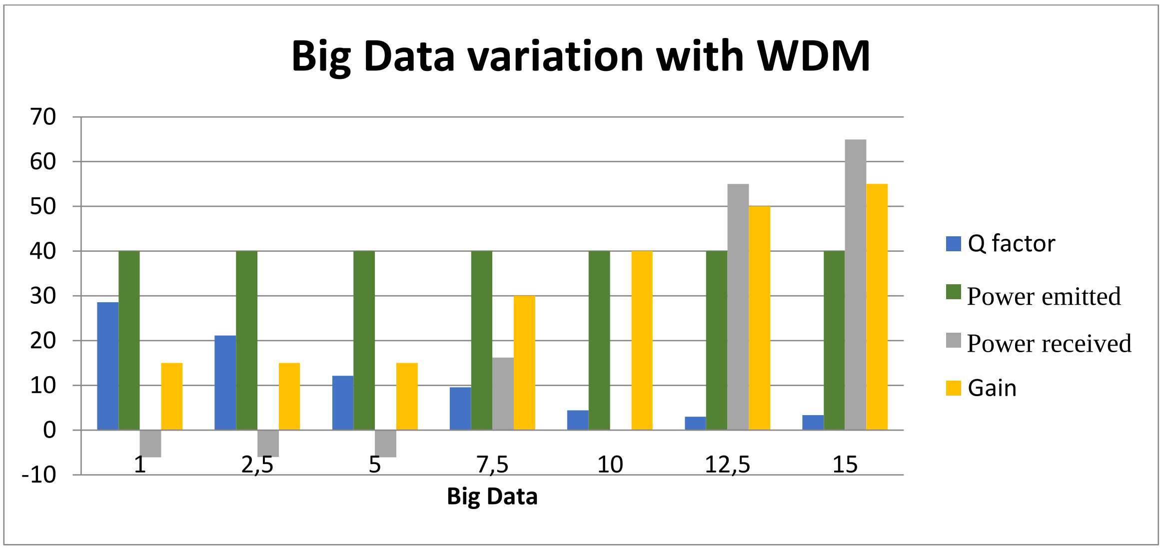


Figure III.22 : Big Data variation with WDM

This graph shows the variation of the Q factors, the transmitted power, the received power and the gain according to the "Big Data" values. With increasing data, there is an increase in the bit error rate (BER), which leads to a deterioration of the quality factor (Q). According to the observations from the simulation, even a throughput of 15 Gbit /s is possible with optical wireless communication. Mays with gain increase

III.5 Conclusion

In this chapter, we were introduced to the OptiSystem software and carried out a simulation using optical wireless communication (OWC) and big data transmission using the WDM 4*1 multiplexer. We studied the variations of BER, Q factor and the power received. We have noticed that Gain plays a major role in these variations. The increase in power transmitted by the Leo satellite results in a more robust signal received on the ground. This gives precision in data transmission.

In conclusion, BIG DATA transmission by laser link from low Earth orbits represents a major technological advancement in the field of communications, this technology opens new possibilities for innovation and improvement of communication systems on a global scale .

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General conclusion

The transmission of large-scale data, often referred to as "Big Data", by laser link in low orbit (LEO) thanks to the exploitation of the capabilities of laser communication and OWC, this strategy allows transfers fast and efficient data transmission over long distances, with minimal latency levels. Additionally, it offers robust and secure connectivity.

In this configuration, low-orbit satellites act as data relays, enabling global connectivity and constant coverage. Laser technology offers extremely high data rates, meeting the increasing bandwidth requirements associated with big data transmission. Additionally, the use of optical wireless links reduces traditional limitations of radio wave communications, such as spectrum congestion and electromagnetic interference.

A major challenge in optical wireless communication between satellites is satellite vibrations, which cause severe pointing errors and negatively affect system performance. Additionally, this performance depends on several parameters such as transmitted power, data rate and antenna aperture, which are analyzed using OptiSystem simulation software .

In this project, the understanding of inter-satellite links and the application of optical wireless communication was deepened. The simulation and modeling of the IsOWC can be carried out using the OptiSystem software between two satellites separated by 400 km, then 600 km, 800 km, 1000 km with a data rate of 1e+010bit/s, and a operating wavelength of 1538, using NRZ modulation.

After we carried out a big data simulation including four optical signals we used the 4x1 WDM multiplexer to combine the four optical signals each using a different optical wavelength with 0.08 channel spacing (ultra dense WDM). (1540 to 1542.4) and with a transmitted power of 40 dbm, and in the receiving part a 4x1 WDM demultiplexer was used which divides the input optical signal into four distinct channels

After seeing the results of the simulation We can deduce that power is an essential element which impacts the quality and reliability of communication. By increasing the power, one can generally improve the quality of the signal received on earth, decrease the errors and increase the Q factor. and when the wavelength of the signal is longer, this leads to an increase in errors. It is possible to see that the Q factor decreases as the distance increases, in an inversely proportional relationship.

In summary, BIG DATA transmission via low-orbit laser link with OWC represents a promising solution to meet the growing needs for fast, reliable and secure connectivity on a global scale. Its potential to transform telecommunications is immense, and its adoption could open the way to new possibilities in diverse areas, from remote communication to space exploration.

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